

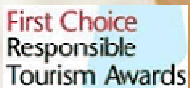
# PROJECT REPORT

Expedition dates: 7 – 13 October 2012  
Report published: May 2013

Underwater pioneers: studying & protecting the unique coral reefs of the Musandam peninsula, Oman.



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UK



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Germany



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Germany



# PROJECT REPORT

## Underwater pioneers: studying & protecting the unique coral reefs of the Musandam peninsula, Oman.

**Expedition dates:**  
7 - 13 October 2012

**Report published:**  
May 2013

**Authors:**  
Rita Bento  
Emirates Diving Association

**Matthias Hammer (editor)**  
Biosphere Expeditions

# Abstract

The Musandam Peninsula, in the Strait of Hormuz, is the only waterway between the Persian Gulf and the Arabian Sea. Corals from this region, where sea temperatures and salinity are high, are more resilient to those environmental parameters than corals in other parts of the world. Nevertheless recent studies suggest that any additional stress may lead to coral die-off.

Biosphere Expeditions has been conducting surveys, using the internationally recognised Reef Check methodology, around the Musandam Peninsula since 2009, studying benthic and fish communities, and anthropogenic impacts. In October 2012, five different sites in north Musandam were surveyed. Survey results are compiled and compared to previous surveys in this report.

Results show a promising, stable reef habitat in north Musandam since surveys began. Slight increases in hard and soft coral cover, as well as high average coral coverage of 60%, well above the Indo-Pacific average of 22%, illustrate the presence in north Musandam of what can nowadays be considered atypically healthy reefs. However, results also show low numbers of some fish and invertebrate populations, most likely due to overexploitation. The stability of Musandam reefs is therefore not secure.

North Musandam doubtless harbours some of the best reefs of the region, but reefs with such high coral coverage are normally able to support fish populations greater than those observed. Musandam reefs, with the right protection, are able to support such healthy fish populations with appropriate age structures, and thus a source-sink systems for fisheries. Healthy reefs with stable fish and invertebrate populations improve the local economy, not only by supporting local artisan fisheries, but also other economies, such as tourism.

We therefore continue to recommend that a marine protected area (MPA), or a network of MPAs, is created in north Musandam. We also urge rapid action before what is at the moment still a unique natural treasure for Oman is degraded and lost.

## المخلص العربي

تعتبر شبه جزيرة مسندم والتي تقع مباشرة على مضيق هرمز والممر والمنفذ المائي الوحيد بين الخليج العربي وبحر العرب، تتميز الشعاب المرجانية في تلك المنطقة بالتكيف الكامل مع درجات الحرارة المرتفعة للمياه وكذلك الملوحة العالية مقارنة بأنواع الشعاب المرجانية في أي منطقة أخرى، بالرغم من ذلك هناك العديد من التحذيرات التي أطلقتها بعض الدراسات الحديثة حيث أشارت أن حالة الشعاب المرجانية بتلك المنطقة حرجة وقد لا تتحمل أي ارتفاع في درجة حرارة المياه أو الزيادة في درجات الملوحة مما قد يستتبع ذلك تدهور حالة الشعاب المرجانية وقد تنتهي بإخفائها من المنطقة.

منذ العام 2009م قامت منظمة بعثات المحيط الحيوي (بيوسفير أكسيديشن) بالعديد من الدراسات البحثية في المنطقة وذلك باستخدام أحدث المعايير الدولية لقياس حالة الشعاب المرجانية حول شبه جزيرة مسندم بالإضافة إلى دراسة الأسماك والكائنات البحرية الأخرى المتواجدة بالمنطقة، وبتاريخ أكتوبر 2012م تم الإنتهاء من دراسة خمسة مواقع مختلفة بشبه الجزيرة وتمت مقارنة البيانات بالإبحاث والدراسات السابقة وعرضها بالتفصيل في التقرير المرفق.

منذ بدء الدراسات الحقلية أظهرت النتائج حالة مستقرة وواعدة للشعاب المرجانية في شمال شبه جزيرة مسندم، لوحظ أن هناك زيادات بسيطة في الغطاء المرجاني المرن والصلب وكذلك ارتفاع متوسط التغطية المرجانية إلى 60% أعلى من 22% المعدل المسجل في المحيطين الهادي والهندي ويوضح ذلك حالة الشعاب المرجانية الجيدة في الوقت الحاضر بمنطقة شبه جزيرة مسندم. بالرغم من ذلك، أظهرت النتائج انخفاض أعداد بعض أنواع الأسماك واللافقاريات بنفس المنطقة وذلك على الأرجح نتيجة للاستغلال المفرط لتلك الموارد الحية وهذا ما يعد مؤشراً وإنذاراً بأن مازال هناك العديد من المخاطر التي تهدد تلك البيئة الحيوية.



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Please note: Each expedition report is written as a stand-alone document that can be read without having to refer back to previous reports. As such, much of this section, which remains valid and relevant, is a repetition from previous reports, copied here to provide the reader with an uninterrupted flow of argument and rationale.

# 1. Expedition Review

M. Hammer (editor)  
Biosphere Expeditions

## 1.1. Background

Biosphere Expeditions runs wildlife conservation research expeditions to all corners of the Earth. Our projects are not tours, photographic safaris or excursions, but genuine research expeditions placing ordinary people with no research experience alongside scientists who are at the forefront of conservation work. Our expeditions are open to all and there are no special skills (biological or otherwise) required to join. Our expedition team members are people from all walks of life, of all ages, looking for an adventure with a conscience and a sense of purpose. More information about Biosphere Expeditions and its research expeditions can be found at [www.biosphere-expeditions.org](http://www.biosphere-expeditions.org).

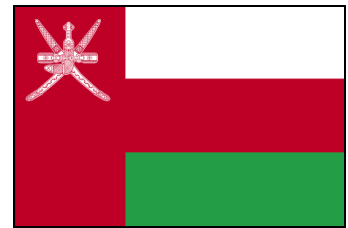
This project report deals with an expedition to the Musandam peninsula that ran from 7 to 13 October 2012 with the aim of monitoring the health of the Musandam peninsula's reefs, its fish and invertebrate communities so that informed management, education and conservation decisions can be made by the government and NGOs. Data on the current biological status of the reefs and of population levels of key indicator species are crucial for educational purposes and to be able to put forward ideas for future marine protection areas. Data collection followed an internationally recognised coral reef monitoring programme, called Reef Check, and will be used to make informed management and conservation decisions within the area. The expedition included training for participants as a Reef Check EcoDiver.

Although popular myth has Arabia down as a vast, flat and empty expanse of sand (and oil), Oman is quite different. In fact, there is a wide range of contrasting landscapes: high mountains, beaches, the desert landscapes of the Empty Quarter, coral reefs and even tropical habitats, where the monsoon touches Oman in the extreme south.

The 650 kilometre coastline of the Musandam peninsula is strewn with rocks and coves, gradual steps, steep rocky slopes and cliffs that plunge to great depths all over the fjord-like landscape. The coral reefs that grow along the margins of this stunning landscape are still relatively untouched as influences such as industrial-scale fishing, pearl or scallop extraction or large numbers of recreational divers have not wreaked their destructive influence there. The area is therefore a prime target for studying intact reef ecosystems, conserving them for future generations and using them in the education of people locally and all over the world.

## 1.2. Research Area

The Musandam peninsula (sometimes also called the Norway of Arabia) is the northernmost part of Oman jutting out into the Strait of Hormuz at the entrance to the Arabian Gulf. The province, or Governorate of Musandam as it is officially known, is separated from the rest of Oman by various parts of the United Arab Emirates including Ras al Khaimah and Fujairah. The Musandam peninsula more or less begins where the mountains rise from the plains of Ras al Khaimah.



Flag and location of Oman and study site.

An overview of Biosphere Expeditions' research sites, assembly points, base camp and office locations is at [Google Maps](#).

The remote and rugged mountains, which rise straight out of the sea creating fjords and stunning landscapes, have had isolated communities for centuries. Many coastal villages can be reached only by boat, as there are no roads on much of the peninsula. Pockets of flat land support subsistence agriculture. The population of approximately 29,000 is concentrated in the capital, Khasab (18,000 in 2004) in the north and Dibba (5,500) on the east coast. Fishing is the principal economic activity supported by employment in government jobs.

### Geology

Rocks of the Hajar supergroup in the north appear to be flat-lying but are actually folded in a north-south trending anticline. Thinly-bedded yellowish-orange dolomitic limestones and mudstones indicating a near-shore environment progress upwards into highly fossiliferous shelf limestones. Shell fragments, brachiopods and micro-fossils in limestone indicate continental shelf conditions. These limestones were deposited from the early Jurassic to the Cretaceous period and are reckoned to be older than 65 million years.

“Round the bend”

The British arrived on a lump of rock they called Telegraph Island in the fjords back in the mid-19th century, staying for five years. They were laying a telegraph cable from India to Basra in Iraq. Taking the cable "round the bend" of the Gulf gave rise to the expression, since living on Telegraph Island in the extreme heat of summer must have sent them crazy! These days, the island is noted for its rich underwater life and dhows (the local type of fishing boat) stop off here.

### 1.3. Dates

The project ran over a period of one week, composed of a team of international research assistants, scientists and an expedition leader. Expedition dates were:

2012: 7 - 13 October

Dates were chosen when survey and weather conditions are most comfortable.

### 1.4. Local Conditions & Support

Expedition base

The expedition base was a modern and comfortable live-aboard dhow with eight air-conditioned cabins, some of them with on-suite toilet and shower facilities. The dhow had three decks, an air-conditioned lounge, a compressor and all facilities one would expect on a modern live-aboard boat. Tank refills and dive services were provided by the crew. A professional cook and crew also provided all meals and vegetarians and special diets could be catered for.

Weather & water temperature

The climate is tropical and maritime. The average day temperature during the expedition was 34 - 37°C, with sunshine and some clouds. Water temperature during the expedition ranged from 28 - 29°C.

Field communications

The live-aboard boat was equipped with a satellite communication system. Mobile phones worked in some parts of the study site. The expedition leader also sent an expedition diary to the Biosphere Expeditions HQ every few days and this diary appeared on Biosphere Expeditions' social media sites such as [Facebook](#), [Google+](#) and the [Wordpress blog](#).

Transport, vehicles & research boats

Team members made their own way to the Dubai assembly point. From there onwards and back to the assembly point all transport and vehicles were provided for the expedition team, for expedition support and emergency evacuations.

## Medical support and insurance

The expedition leader and the expedition scientist were trained first aiders, and the expedition carried a medical kit. The standard of medical care in Oman is very high with a clinic in Khasab. There is also a recompression chamber in Muscat and one in Dubai. Safety and emergency procedures were in place. There were no serious medical incidences during the expedition and emergency procedures did not have to be invoked.

## Diving

The minimum requirement to take part in this expedition was a PADI Open Water or equivalent qualification. Team members who had not dived for twelve months prior to joining the expedition were required to complete a PADI Scuba Review before joining the expedition.

Standard PADI diving and safety protocols were followed.

Dive groups were divided into different teams, each working on specific areas of survey work. Divers were allocated to teams based on a mixture of personal preference, diving skills and knowledge of the species.

### 1.5. Local Scientist

Biosphere Expeditions was working with Rita Bento of the Emirates Diving Association on this project. Rita Bento was born in Portugal. She has a degree in Marine Biology from the University of the Azores and a Masters in Science of the Sea – Sea Resources from Porto University and is currently doing her PhD with Porto University. Her first area of research was bioacoustics of baleen whales, working in the USA with Oregon State University and NOAA (National Oceanographic and Atmospheric Administration). In the last few years she has focussed her research on Marine Protected Areas (MPA) and coral reefs ecology. Rita is also a Reef Check Course Director with hundreds of Reef Check dives. Besides her scientific career, she is also a CMAS diving instructor and published the first Portuguese diving guide in 2007.

### 1.6. Expedition Leaders

The expedition was led by Dr. Matthias Hammer, who founded Biosphere Expeditions in 1999. Born in Germany, he went to school there, before joining the Army at 18, and serving for several years amongst other units with the German Parachute Regiment. After active service he came to the UK and was educated at St Andrews, Oxford and Cambridge. During his time at university he either organised or was involved in the running of several expeditions, some of which were conservation expeditions (for example to the Brazil Amazon and Madagascar), whilst others were mountaineering/climbing expeditions (for example to the Russian Caucasus, the Alps or the Rocky Mountains). With Biosphere Expeditions he has led teams all over the globe. He is a qualified wilderness medical officer, ski instructor, mountain leader, divemaster and survival skills instructor. Once a rower on the international circuit, he is now an amateur marathon runner and Ironman triathlete.



Adam Stickler joined as assistant leader. Adam was born in Paris and has since lived in the UK and Kenya. Adam studied Biology and is also a PADI qualified diving instructor. He has cycled extensively across Europe and Africa as well as driven a hatchback from England to Mongolia. He is a first aid instructor and a qualified lifeguard. A passion for culture, wildlife and conservation has driven him to discover more about the world we live in and how we can preserve it.

### **1.7. Expedition Team**

The expedition team was recruited by Biosphere Expeditions and consisted of a mixture of all ages, nationalities and backgrounds. They were (with country of residence):

7 – 13 October 2011

Kelvin Aitken (journalist, Australia), Nasr Albusaidi (Oman), Daryle Hardie (Oman), Kathleen Humphrey (USA), Jennifer Lee (USA), Tina Lehmuskoski (Finland), Eric Moore (USA), Andreas Odey (Germany), Michael Preston (USA), Alison Randall (UK), Heidi Richardson (UK).

Crew during the expedition: Ali (boat captain), Poli (cook), Chandu (deck hand), Mohammed (deck hand).

### **1.8. Other Partners**

On this project Biosphere Expeditions is working with Reef Check, the Emirates Diving Association, local dive centres, businesses & resorts, the local community, Sultan Qaboos University, the Oman Ministry for Environment and Climate Affairs, the Oman Tourism Board, as well as the United Nations Environment Programme, the World Conservation Monitoring Centre and the International Coral Reef Action Network (ICRAN).

## 1.9. Expedition Budget

Each team member paid towards expedition costs a contribution of £1,130 per person per 7 day slot. The contribution covered accommodation and meals, supervision and induction, special non-personal diving and other equipment and air, and all transport from and to the team assembly point. It did not cover excess luggage charges, travel insurance, personal expenses such as telephone bills, souvenirs etc., as well as visa and other travel expenses to and from the assembly point (e.g. international flights). Details on how this contribution was spent are given below.

<b>Income</b>	£
Expedition contributions	10,635
Grants & sponsorship	3,000
<b>Expenditure</b>	
Research vessel includes all board & lodging, ship's crew, fuel & oils, other services	6,012
Transport includes transfers & visas	777
Equipment and hardware includes educational & research materials & gear purchased in UK & Middle East	775
Staff Includes local and international salaries, travel and expenses	2,033
Administration includes registration and other admin fees	243
Team recruitment Musandam as estimated % of PR costs for Biosphere Expeditions	6,400
<b>Income – Expenditure</b>	<b>- 2,605</b>
<b>Total percentage spent directly on project</b>	<b>119%*</b>

\*This means that in 2012, the expedition ran at a loss and was supported over and above the income from the expedition contributions by Biosphere Expeditions.

## 1.10. Acknowledgements

This study was conducted by Biosphere Expeditions which runs wildlife conservation expeditions all over the globe. Without our expedition team members (who are listed above) who provided an expedition contribution and gave up their spare time to work as research assistants, none of this research would have been possible. The support team and staff (also mentioned above) were central to making it all work on the ground. Thank you to all of you, and the ones we have not managed to mention by name (you know who you are) for making it all come true. Biosphere Expeditions would also like to thank members of the Friends of Biosphere Expeditions and donors, Swarovski Optik, Motorola and BUFF® for their sponsorship. Biosphere Expeditions also gratefully acknowledges grant support from the Waterloo Foundation.

## 1.11. Further Information & Enquiries

More background information on Biosphere Expeditions in general and on this expedition in particular including pictures, diary excerpts and a copy of this report can be found on the Biosphere Expeditions website [www.biosphere-expeditions.org](http://www.biosphere-expeditions.org).

Enquires should be addressed to Biosphere Expeditions via [www.biosphere-expeditions.org](http://www.biosphere-expeditions.org).

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## 2. Reef Check Survey

Rita Bento  
Emirates Diving Association

### 2.1. Introduction

#### Study site description

The Musandam peninsula, also known as Ru'us al-Jibal, is an exclave of Oman separated from Oman by the United Arab Emirates. It is situated on the Arabian Peninsula in the Strait of Hormuz, the narrow passage that links the Arabian Gulf and the Gulf of Oman (Rezai et al. 2004).

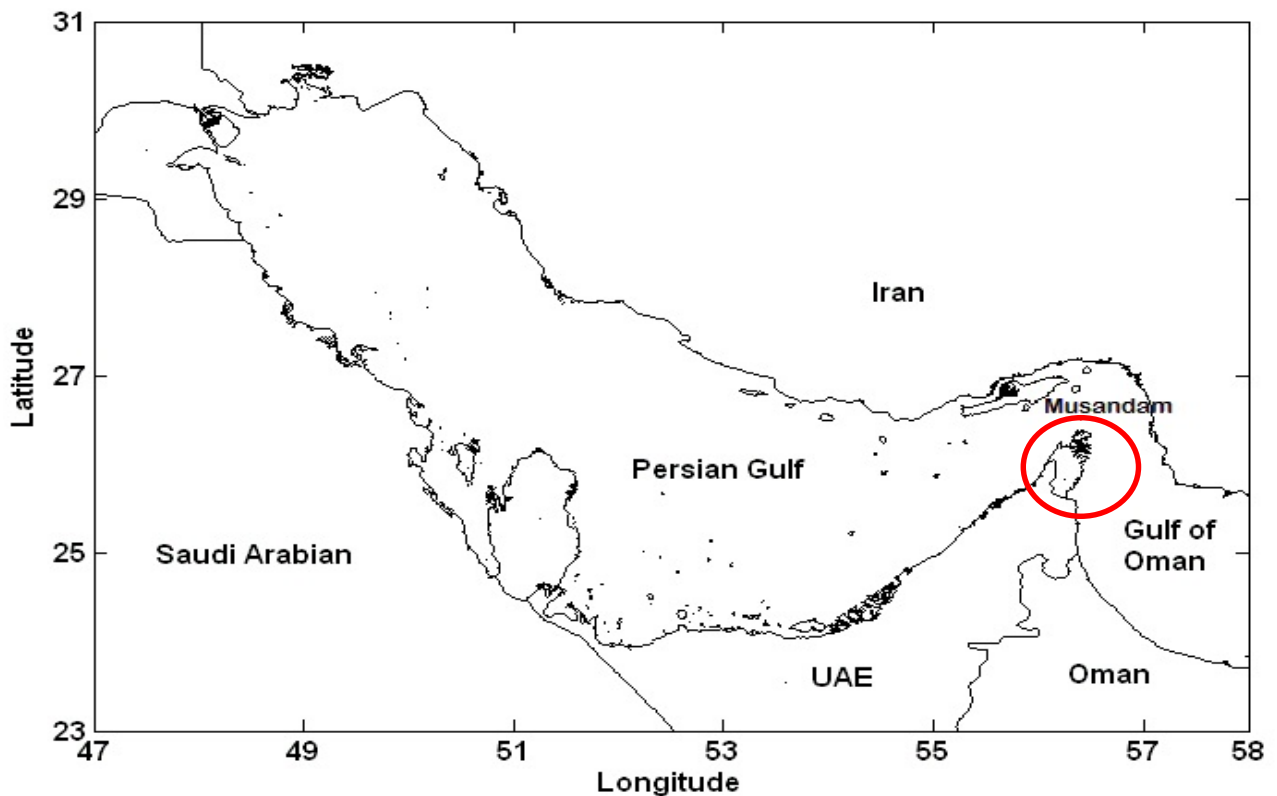


Figure 2.1a. Location of the Musandam peninsula in the Middle East.

The Persian Gulf is a shallow semi-enclosed basin measuring about 1,000 km by 200 - 300 km. It has an average depth of 35 meters, dipping down towards the north to a maximum of about 60 meters near Iran, and inclined downwards to about 100 meters deep at its entrance in the Strait of Hormuz, the only connection to the Gulf of Oman and the Indian Ocean (Carpenter et al. 1997, McClanahan et al. 2000, Pilcher et al. 2000, Sheppard et al. 1992).

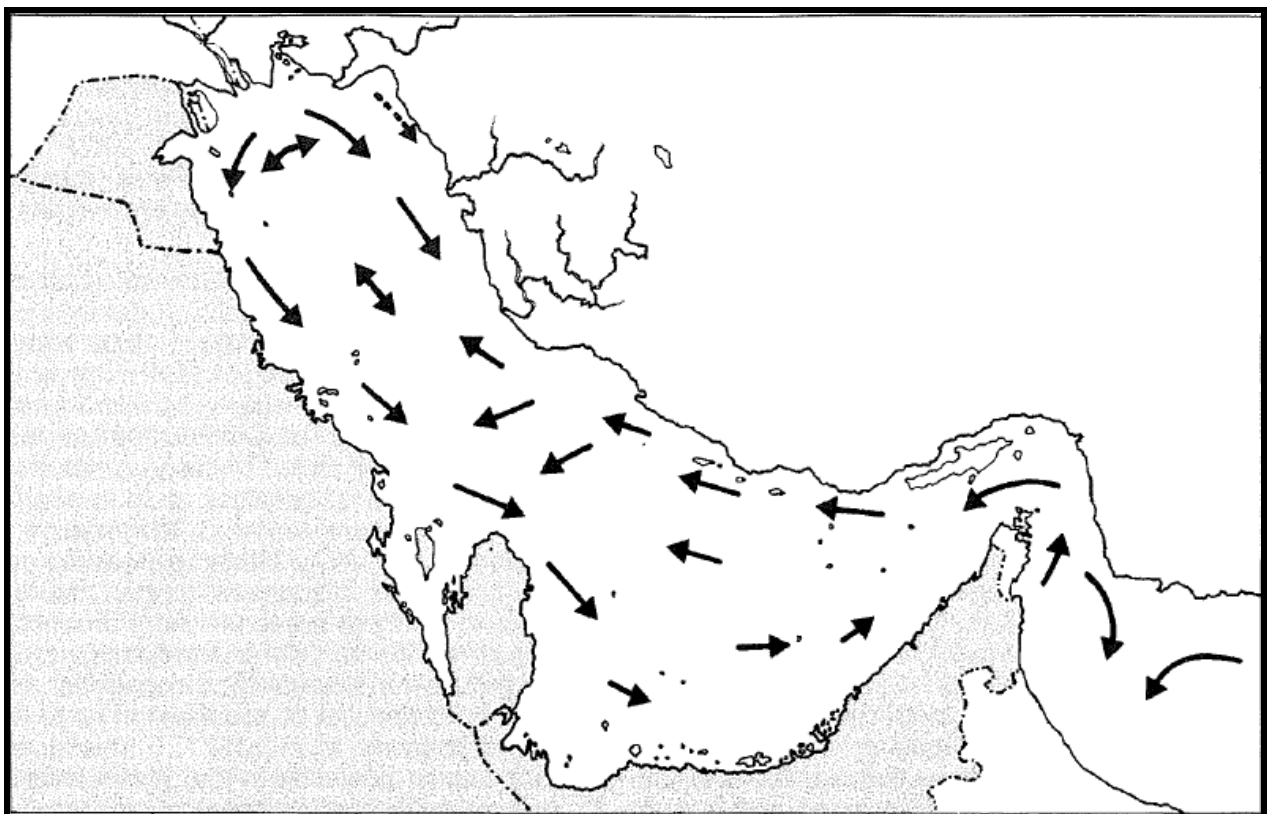


As a result of its shallow depth and restricted water exchange, the Persian Gulf is characterised by strong variations in sea surface temperatures (SSTs), ranging from 12°C in winter and 36°C in the summer, and high salinity values of 43 (no unit) year-around, hereby influencing water density, currents, water mixing, and a host of other environmental parameters that therefore influence species composition (Coles 2003, Price et al. 1993, Riegl, 2001). In contrast with the Persian Gulf, the Gulf of Oman and Arabian Sea are deep seas (more than 2,000 meters deep) with more stable conditions (Wilson et al. 2002).

The Arabian Peninsula is among the hottest areas in the world, where temperatures above 49°C have frequently been recorded at some weather stations in the region (SOMER 2003). The extremely arid nature of the Arabian region, the high temperatures and the constant and intensive sunshine, especially along the coastal areas, results in some parts in a lack of four season variability.

The region lies at the edge of two global weather systems, the Asian and the North Africa weather systems, whose fluctuations cause varied and severe environmental conditions, the summers are hotter and the winters colder than most subtropical zones (Carpenter et al. 1997, McClanahan et al. 2000, Sheppard et al. 1992).

Evaporation by dry winds is as intense in winter as it is during the hot summer. Over the whole Persian Gulf, evaporation averages 144 to 500 cm/yr, most occurring in the shallow bays in the south where evaporation locally exceeds 2000 cm/yr. In these shallow bays salinity exceeds 50 over hundreds of square km, exceeding even 70 in large expanses (McClanahan et al. 2000). These large evaporation rates over the Persian Gulf lead to the formation of a warm and salty water masses, which flow into the Gulf of Oman through the Strait of Hormuz; the mass and salt budget in the Gulf are closed by an inflow of Indian Ocean surface water coming from the northern Arabian Sea (Figure 2.1b) (Pous et al. 2004).



**Figure 2.1b.** Major current patterns of the Persian Gulf and northern Arabian Sea (Reynolds 1993).

Tides in the Gulf of Oman and the Arabian Sea are oceanic in type where frictional effects are minimal. Tide heights can range from 1.5 metres, in the Arabian Sea, to 2.5 metres in the Gulf of Oman, being predominantly semi diurnal and correlating closely with that of the Indian Ocean. But generally, tidal height is not very marked anywhere in the region, and ranges of 0.25 to 0.75 metres are most common although tidal height can rise near land, especially in the far north and just outside the Strait of Hormuz (Sheppard et al. 1992).

In the Gulf of Oman water temperatures are moderate in comparison to the Arabian Gulf. Typical winter surface water temperatures fall to 22 - 23°C (minimum recorded of 12°C), while summer temperature is characterised by a highly fluctuating regime caused by the rise and fall of a shallow, but strong thermocline. Summer water temperatures range between 23 - 31°C (maximum recorded of 35°C), and can often cover this range within one day (Rezai et al. 2004). In the Arabian Sea the seasonally reversing winds induced by the monsoon create a strong upwelling, which causes the remarkable, low sea temperatures off the southeast Arabia peninsula in the hottest summer months (Carpenter et al. 1997; Sheppard et al. 1992). In the Gulf of Oman the cool water influences are less constant, although occasional upwellings occur and can replace surface waters very rapidly such that falls of up to 10°C over one or two days can happen. Such upwellings have a significant impact on the marine ecology, and therefore areas of reef development are few (Randall 1995; Spalding et al. 2001).

Salinity in the Gulf of Oman is generally at 36.5, but due to the influence of the Arabian Gulf 38.9 has been recorded in the surface waters of the Strait of Hormuz, in the Musandam peninsula, to Ra's Al-Hadd at the entrance to the Gulf of Oman (Rezai et al. 2004).

Salinity values experienced in the Persian Gulf exceed the optimum range of coral reef in other tropical regions in the Atlantic and Pacific that normally show a salinity interval of 35 to 37 and an upper tolerance range between 40 and 45 (Coles 2003; Price et al. 1993). The SSTs values observed in the Persian Gulf are the highest encountered worldwide on reefs, varying by up to 25°C annually (Coles 2003; Sheppard and Loughland 2002). In other tropical regions the changing range is normally 19°C only, with the normal upper limits between 33°C and 34°C and the lower limits between 13 to 16°C (Coles 2003). Species that establish populations in the area must therefore be capable of withstanding the stress of osmotic and temperature extremes. Many major shallow water taxonomic groups and species that are prevalent at similar latitudes elsewhere in the Indo-Pacific, and found in adjacent seas, are completely lacking in the area (Carpenter et al. 1997).

Although thought not to be present in extreme conditions beyond 23.5° north and south of the equator, the coral reefs found in the Arabian region are a unique example of adaptation by marine organisms (SOMER 2003). The range of environment, latitude and geological formation combine to produce very varied coral habitats within this region. This results in several different coral communities, which are distributed according to geographic location and depth (Sheppard et al. 1992).

Some corals have the ability to acclimatise by phenotypic changes to more stressful environmental conditions, resulting in the readjustment of the organism's tolerance levels. They have evolved temperature thresholds close to the average upper temperatures of their area, so thermal tolerance varies from region to region. Similar corals in each location live under quite different temperature regimes and thus have different thermal tolerances (Grimsditch and Salm, 2006, Marshall and Schuttenberg 2006).

Corals and reef communities in some areas (such as the Persian Gulf and Gulf of Oman) tolerate salinity and temperature conditions that are lethal when imposed rapidly on the same species in less extreme environments (Baker et al. 2004, Buddemeier et al. 2004, Riegl et al., 2006).

Rezai et al. (2004) describe coral communities of the Gulf of Oman and Arabian Sea as in good condition, due in part to the mitigating effects of a summer upwelling that cools summer seawater temperatures, possibly protecting the corals from bleaching.

There is a fairly distinct Arabian coral species grouping, and within it, there is a single, principal division into a Red Sea group and a Gulf of Oman/Arabian Sea group, which then fuses with the Persian Gulf (Sheppard et al. 1992). Although the species composition of Persian Gulf corals is typically Indo-Pacific, with a few regional endemics, the coral diversity in the Persian Gulf and parts of the Gulf of Oman is relatively low compared to most parts of the Indian Ocean where it is up to four times higher (Rezai et al. 2004, Riegl 1999). Of the 656 species among 109 genera of zooxanthellate corals for the Indo-Pacific, only about 10%, or 68 species among 28 genera, occur in the Persian Gulf and 120 species among 33 genera in the Gulf of Oman (Rezai et al. 2004). Some combination of factors has probably limited the recruitment, settlement, survival and growth of reef corals in the region, eliminating many species and perhaps favouring a few that are adapted to the uniquely harsh conditions of the region (Coles 2003).

Due to the varied coastline of Oman, where upwelling effects are attenuated by bays, reef growth continues with typically reef flat and reef slope development. Even where reefs do not develop, prolific coral communities grow on many different types of non-limestone rock. Some coral growths develop into vast monospecific beds to a degree seen only in a few other cases in Arabian seas. Numerous areas of exposed, hard substrate are not dominated or even colonised by hard corals; instead soft corals and macroalgae generally dominate (McClanahan et al. 2000).

Even though the Persian Gulf's corals are unique and seem to endure extremely harsh conditions when compared to corals in other parts of the world, scientists are increasingly concerned that any additional stress, imposed by global climate change or regional coastal development may accelerate coral die-off (EWS-WWF 2008, Wilkinson 2004). Reefs in the Persian Gulf have been devastated by major coral bleaching events (in 1990, 1996, 1998 and 2002) and recently by extensive coastal developments along the Arabian Peninsula (Burt et al. 2008, Wilkinson 2008). The impact extends beyond the shoreline, since turbidity and suspended sediments are dispersed from the dredge or reclamation sites. In addition, coastal currents are diverted by coastal engineering, altering the movement of sediments causing them to accumulate (Rezai et al. 2004).

The coral reef losses from climate-related devastation and massive coastal development on the Arabian Peninsula have made this region amongst the most damaged in the world with the lowest predictions for recovery. According to recent estimates, 30% of the coral reefs are at a threatened-critical stage and up to 65% of the coral reefs may have been lost already due to natural causes (fluctuation of temperatures, diseases) and anthropogenic stresses (oil pollution, unmanaged coastal development, unregulated commercial and recreational fishing and diving) (Wilkinson 2004). Unfortunately coral reef research and monitoring is often way behind other parts of the world (Wilkinson 2008).

In the past decades there have not been many studies on the Musandam peninsula coral reefs biodiversity. The latest research in the region that collected data in the Musandam peninsula includes different topics such as tropical harmful algal blooms (Bauman et al. 2010), kingfish fisheries (Claereboudt et al. 2004), shark fisheries (Henderson et al. 2007) and phytoplankton (Subba-Rao and Al-Yamani 1998). But the last published scientific study done exclusively in Musandam was conducted in 1971 and 1972 (Fraser et al. 1973).

#### Additional external factors affecting the area

On 6 June 2007 the first documented tropical storm occurred in the Arabian Sea. Tropical cyclone Gonu was a category 5 storm and matched the strongest storm recorded in the northern Indian Ocean (Mooney 2007, UNEP 2008). The human and economic costs of cyclone Gonu were considerable with about 75 deaths and 2.88 billion € (Euros) of damage. In Oman, including Musandam, and on the east coast of the UAE damage by the strong waves along the coast were noted. Corals on exposed shores were almost entirely destroyed and there was variable damage in sheltered bays, coves and islands. Before this natural catastrophe the Musandam Peninsula reefs were dominated by *Porites* and *Acropora*.

Rich coral communities such as *Porites lutea*, *P. solida*, *Acropora valenciennesi* and *A. valida* were common from Musandam to the capital area of Oman (McClanahan et al. 2000; Sheppard et al. 1992). Gonu affected colonies down to 7 meters with major impacts on *Sinularia*, *Sarcophyton* and *Acropora*. By March 2008 there was significant re-growth of some soft coral areas, although hard coral communities in shallow exposed areas have shown less resilience (Wilkinson 2008).

The existence of a harmful algal bloom (HAB), caused by the algal species *Cochlodinium polykrikoides*, between August 2008 and May 2009, when the marine life was still recovering from the cyclone Gonu, significantly changed the habitats and biodiversity in the area. Both the Persian Gulf and Gulf of Oman have a high phytoplankton biodiversity with 38 taxa potentially bloom-forming or harmful (Subba-Rao and Al-Yamani 1998). The presence of *C. polykrikoides* in the region was noticed for the first time during this period in 2008 and 2009. A pattern of subsequent recurrence of *C. polykrikoides* blooms has been observed in other parts of the world, suggesting that this species may become a persistent HAB problem in the region and further monitoring and protection in Musandam is needed according to Richlen et al. (2010). It is known that increasing human population and demand for resources and development is one of the main reasons for the rise in the distribution and size of harmful algal blooms and dead zones around the globe (Anderson 1997, Hinchley et al. 2007). Ballast water carried in ships has also been recognised as one of the main vectors for the translocation of non-indigenous marine organisms around the world. Based on preliminary analysis, it is suspected that the HAB on the east coast of the UAE and Oman from August 2008 to May 2009 was due to a non-native algae species and therefore that ballast water discharge was involved at some point (Richlen et al. 2010).

#### Reef Check

Reef Check's survey method uses simple techniques to collect scientifically robust data. This methodology is specially designed for recreational divers that might not have scientific background, so training has to be precise, rapid and understandable in order to guarantee that organism identification is accurate (Hodgson et al. 2006).



To understand the health of a coral reef, Reef Check bases its data collection on “indicator organisms” that are defined as organisms that reflect the conditions of the ecosystem. These indicators can be individual species or even a family. The important thing is that each of these indicators has an economic or ecological value, is sensitive to anthropogenic impacts and easy to identify. A Reef Check team collects four types of data (Hodgson et al. 2006):

1. A site description referring to environment, socio-economic and human impact conditions;
2. Fish indicator species count;
3. Invertebrate indicator species count;
4. Recording different substrate types (including live and dead coral).

Data for points 2-4 are collected along a 100 metre transect, at two depth contours, between 2 to 5 metres and between 6 and 12 metres (Hodgson et al. 2006). Data for point 1 is collected prior and after the dive.

### Aims and objectives

The primary aim of this project was to provide data on the health of the Musandam Peninsula's coral reefs and current threats. With the beginning of this project in 2009 it was possible, for the first time in Musandam, to collect data through Reef Check surveys in order to quantitatively assess benthic and fish communities and anthropogenic impacts. The data collected are now useful for comparison with the survey conducted in 2009, as well as future surveys, and to provide data from Musandam for the global Reef Check database.

## 2.2. Methods

### Site selection & sampling design

Between 7 and 13 October, 2012, five different sites in North Musandam were surveyed (Figure 2.2a). All sites had been recorded by Global Positioning System (GPS) during the 2009 expedition and have been used since then for possible comparative Reef Check surveys every year. All positions were collected in degrees, minutes and seconds (Table 2.2a).

All the dive sites surveyed during the 2012 expedition were located in the North region of the Musandam Peninsula and included diving sites that are well-known diving spots regularly visited by divers, as well as areas that are known for their importance to fisheries. With all the dive sites located in the North area of Musandam we will be able to compare changes that might exist since 2009 in this area of Musandam.

### Training of expedition team members

All data were collected by team members that passed through an intensive Reef Check training and testing procedure. Team members on the expedition were coordinated by a project scientist and an expedition leader. The primary responsibilities of both were to train the team members in Reef Check methodology and also to coordinate and supervise the subsequent surveys and data collection.

## Survey procedures & data collection

The Reef Check survey protocol utilises two transects at depths between 2 - 5 metres (shallow dive) and 6 - 12 metres (medium dive), chosen for practical reasons of dive duration and safety. Along each depth interval, shallow and medium, four 20 metre long line transects are surveyed with a 5 metre space interval between transects. The distance between the start of the first transect and end of the last transect is, therefore, 95 metres.

An ideal Reef Check team includes six members (three buddy pairs, each pair responsible for fish, invertebrate and substrate data collection respectively) plus support crew, each with different specialties and experience.

The Reef Check methodology is adapted by region, and the area used for this expedition was the Indo-Pacific region. Full details of the methodology and regular updates can be found on the Reef Check website [www.reefcheck.org](http://www.reefcheck.org).

Note that during this expedition the dives were conducted only on the North area of the Musandam Peninsula. Therefore for this report only data from 2009 to 2012 collected in the same dive sites were used.

**Table 2.2a.** Names and geographic coordinates of the 5 dive sites where Reef Check surveys were undertaken.

Site name	GPS log number	Coordinates	
Ra's Shuraytar	D3	N 26°23'04"	E 056°22'46"
Coral Garden	D7	N 26°22'33"	E 056°24'59"
Eagle Bay	D9	N 26°22'55"	E 056°25'06"
Khayl Island	D13	N 26°21'56"	E 056°27'08"
Faqadar Bay	D19	N 26°20'50"	E 056°28'51"



Figure 2.2a. Location of the 5 dive sites surveyed in the North Musandam Peninsula.

## Fish belt transect

Four segments of 5 meters height, 5 m width by 20 m length (centred on the transect line) were sampled for fish that are typically targeted by fishermen or aquarium collectors and that are sensitive to impacts. In the Indo-Pacific these species and families are any grouper (Serranidae) over 30 cm, sweetlips (Haemulidae), snappers (Lutjanidae), parrotfish (Scaridae) over 20 cm, butterflyfish (Chaetodontidae) and moray eel (Muraenidae). Quantitative counts were made of each species/family. Three more species are counted in the Indo-Pacific Reef Check, but were not taken as species to look for since they do not exist in the Musandam area: the Barramundi cod (*Cromileptes altivelis*), the Humphead wrasse (*Cheilinus undulates*) and the Bumphead parrotfish (*Bolbometopon muricatum*).

The same four 5 m wide by 20 m long transects (centred on the transect line) were also sampled for invertebrate taxa typically targeted as food species or collected as curios. The taxa counted were: banded coral shrimp (*Stenopus hispidus*), long-spined black sea urchins (*Diadema* spp.), pencil urchin (*Eucidaris* spp.), collector urchin (*Tripneustes* spp.), three edible sea cucumbers species (*Theleota ananas*, *Stichopus chloronotus*, *Holothuria edulis*), lobster (all edible species) and triton shell (*Charonia tritonis*). Quantitative counts were made of each species/family. The giant clam (*Tridacna* spp.) was not included in the species to count since it does not exist in the Musandam Peninsula area.

During the invertebrate survey, anthropogenic impacts were also assessed. These included coral damage by anchors, dynamite, or 'other' factors, and for trash. Trash is divided by type, i.e. fishing nets or simply 'other'. Divers valued the damage caused by each factor using a 0 to 3 scale (0 = none, 1 = low, 2 = medium, 3 = high).

The percentage cover of bleaching and coral disease in the coral reef (colony and population) was also measured along each 20 meter transect.

## Substrate line transect

Four 20 m long transects were point sampled at 0.5 m intervals to determine the substratum types on the reef. The categories recorded at each 50 cm point were according to Reef Check definitions: hard coral (HC), soft coral (SC), recently killed coral (RKC), nutrient indicator algae (NIA), sponge (SP), rock (RC), rubble (RB), sand (SD), silt (SI) and other (OT).

## Data analysis

All data were entered on underwater slates and subsequently transferred onto Reef Check Excel sheets. Belt transect data were used to calculate the mean abundance of each fish and invertebrate taxa. The substrate line transect data were converted to mean percentage cover of each substratum category. Anthropogenic data were represented by mean abundance of each impact.

Fish, invertebrates and substrate data were tested using one-way ANOVAs with post-hoc Tukey's test to assess differences in abundance between the past four years of surveys. Percentage cover data from the substrate survey were arcsine square-root transformed to improve normality and data from fish and invertebrate surveys were log<sub>10</sub> transformed prior to analyses. For impacts, ordinal data, Kruskal-Wallis ANOVA test were used to assess differences between the four years of surveys.



Note on statistical conventions: the results of statistical tests are given by showing the 'p' (probability) value of the test. Results that are significant at the  $p < .05$  level are commonly considered statistically significant, and  $p < .005$  or  $p < .001$  levels are often called "highly" significant.

## 2.3. Results

### Site description

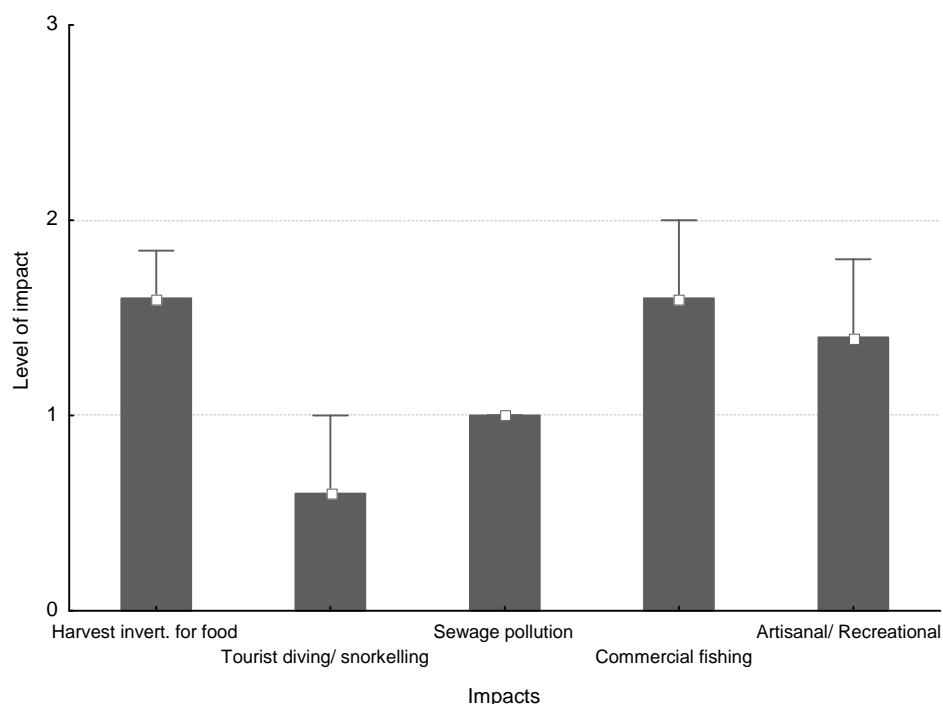
Basic oceanographic and climatic conditions recorded during the 2012 expedition presented similar values to previous years, with warm seawaters and air temperatures. Visibility, as usual in the region, was low (Table 2.3a).

**Table 2.3a.** Average values of air temperature, sea surface temperature and visibility during the Musandam expedition from 2009 to 2012 (values with standard error) and the respective minimum and maximum values registered in 2012.

	2009	2010	2011	2012	Min – Max 2012
Air temperature	34.2 ± 0.1°C	32.6 ± 0.4°C	34.8 ± 0.2 °C	36.0 ± 0.5 °C	34 – 37 °C
Sea surface temperature	27.8 ± 0.3°C	30.0 ± 0.3°C	28.6 ± 0.4 °C	28.4 ± 0.2 °C	28 – 29 °C
Visibility	9.3 ± 0.8 m	11.9 ± 1.0 m	8.0 ± 1.0 m	10.2 ± 1.2 m	6 – 11 m

Data collected before each survey, for the Site Description Sheet, are essential for interpreting local and national trends in the dataset, helping to understand the impacts and local knowledge of the area.

Harvesting of marine resources, such as commercial and artisanal fishing, as well as harvesting of invertebrates were the strongest impacts found. Diving activity was of least concern, with low level of impacts (Figure 2.3a).



**Figure 2.3a.** Average level of impacts found in North Musandam, 2012 surveys, during site description. (Level of impacts: 0=none, 1=low, 2=medium and 3=high). Lines represent standard error.

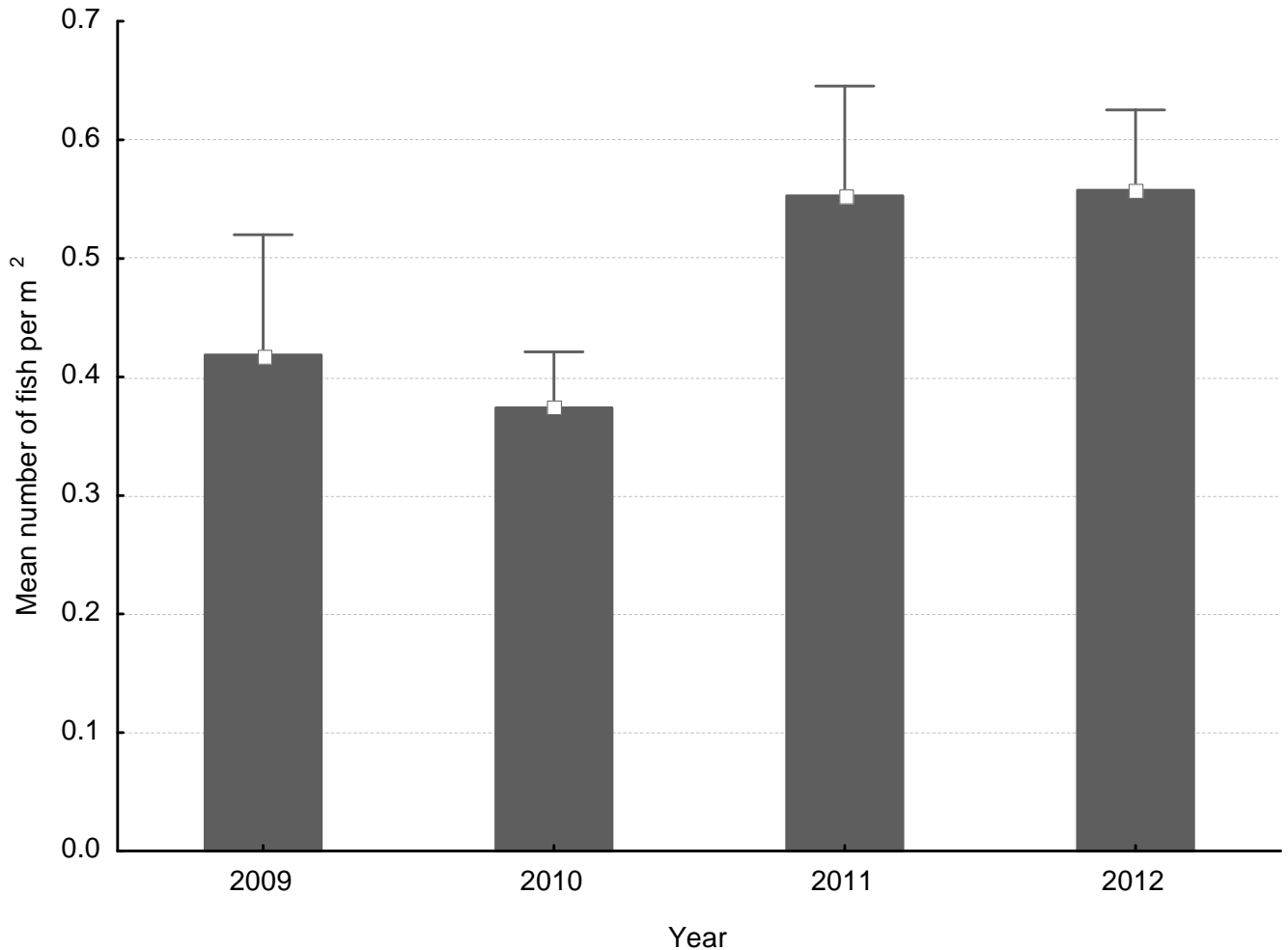
The impacts found in each dive site have changed considerably since 2011. There has been a surprising drop in the diving activity of all dive sites, and an increase in commercial and artisanal fishing in some of the sites studied. It should be noted that the data gathered in the site descriptions are anecdotal. These results should be used to understand the uses and knowledge of the local population about the area and not as a result of the actual impacts on underwater habitats.

**Table 2.3b.** Level of general impacts found on the 5 dive sites surveyed in North Musandam, 2012. Different values found in 2011 are shown in parentheses. Where an increase in impact level was noticed, the related field is coloured red; where a reduction in level of impacts was noticed the related field is coloured green.

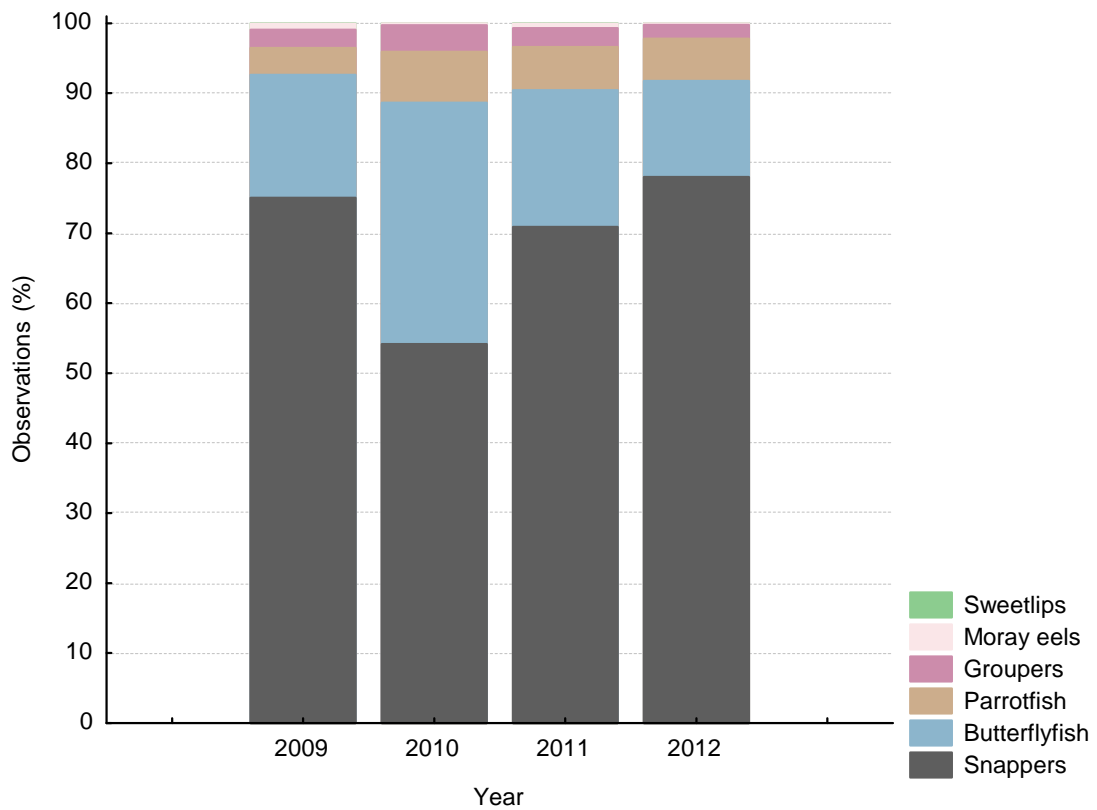
Site name	Harvest invert. for food	Tourist diving/ snorkelling	Sewage pollution	Commercial fishing	Artisanal/ Recreational
Ra's Shuraytar	Low (Medium in 2011)	None (Medium in 2011)	Low	Medium (None in 2011)	Medium (None in 2011)
Coral Garden	Medium (None in 2011)	Low (Medium in 2011)	Low	None (Medium in 2011)	Low
Eagle Ray	Medium	Medium	Low (None in 2011)	None (Low in 2011)	None (Medium in 2011)
Khayl Island	Low (Medium in 2011)	None	Low	Medium (None in 2011)	Medium
Faqadar Bay	Medium (Low in 2011)	None (Low in 2011)	Low	Medium (Low in 2011)	Medium (Low in 2011)

## Fish community

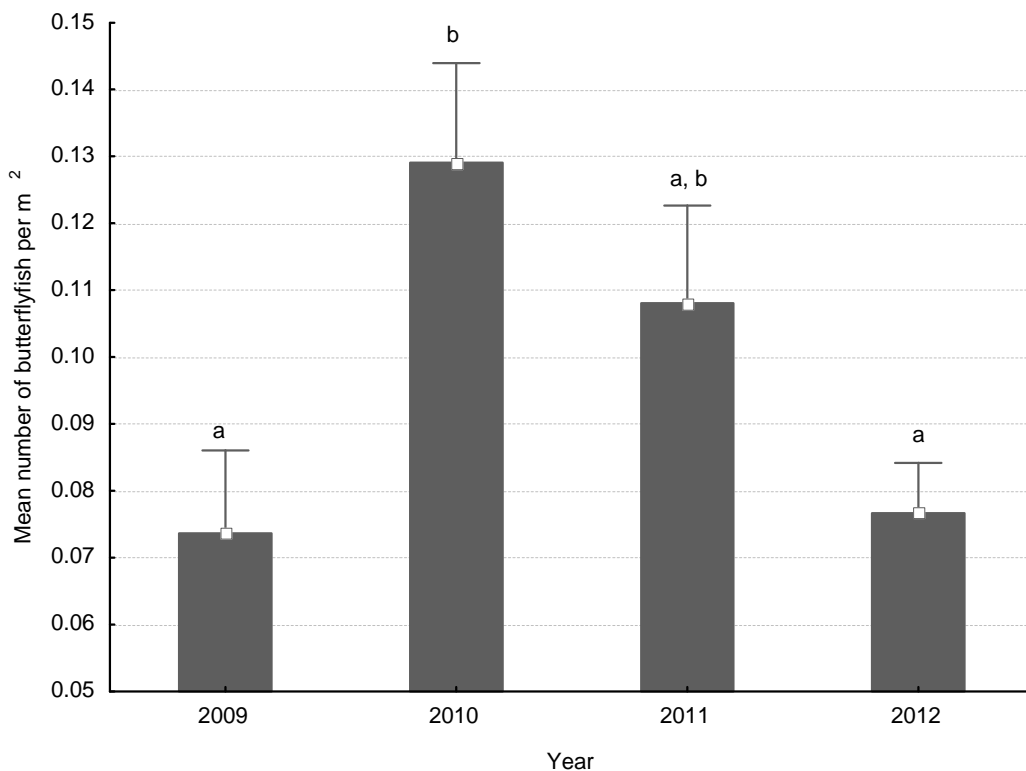
Fish population surveys continue to show low numbers of fish observations per square meter, with no statistical differences since 2009 (Figure 2.3b). The main family observed in north Musandam was Lutjanidae (snappers), followed by much lower observations of Chaetodontidae (butterflyfish) and Scaridae (parrotfish) (Figure 2.3c). Although butterflyfish were the second most observed family, a significant decrease in the population was noticed from 2010 (ANOVA  $F_{(3, 136)} = 4.55, p < .005$ ) (Figure 2.3d).



**Figure 2.3b.** Mean abundance of fish per m<sup>2</sup> in north Musandam, from 2009 to 2012. Lines represent standard error.



**Figure 2.3c.** Composition of the total fish observations in north Musandam, from 2009 to 2012. Values presented in percentages. Note the very low grouper, parrotfish and moray eel presence.

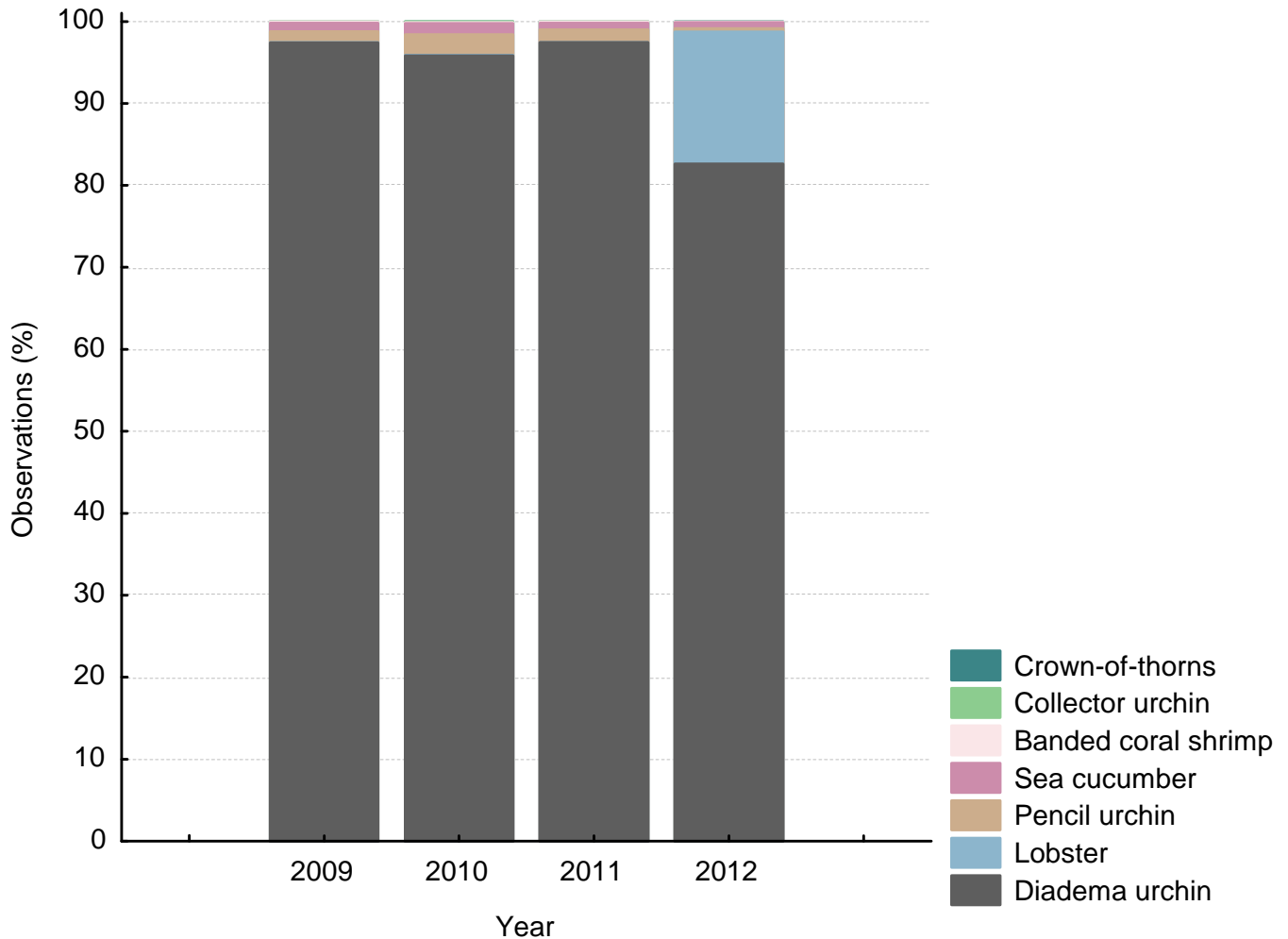


**Figure 2.3d.** Mean number of butterflyfish per m<sup>2</sup> in north Musandam, from 2009 to 2012. Lines represent standard error. Bars with different letters indicate significant differences (Tukey's tests, p<.05)

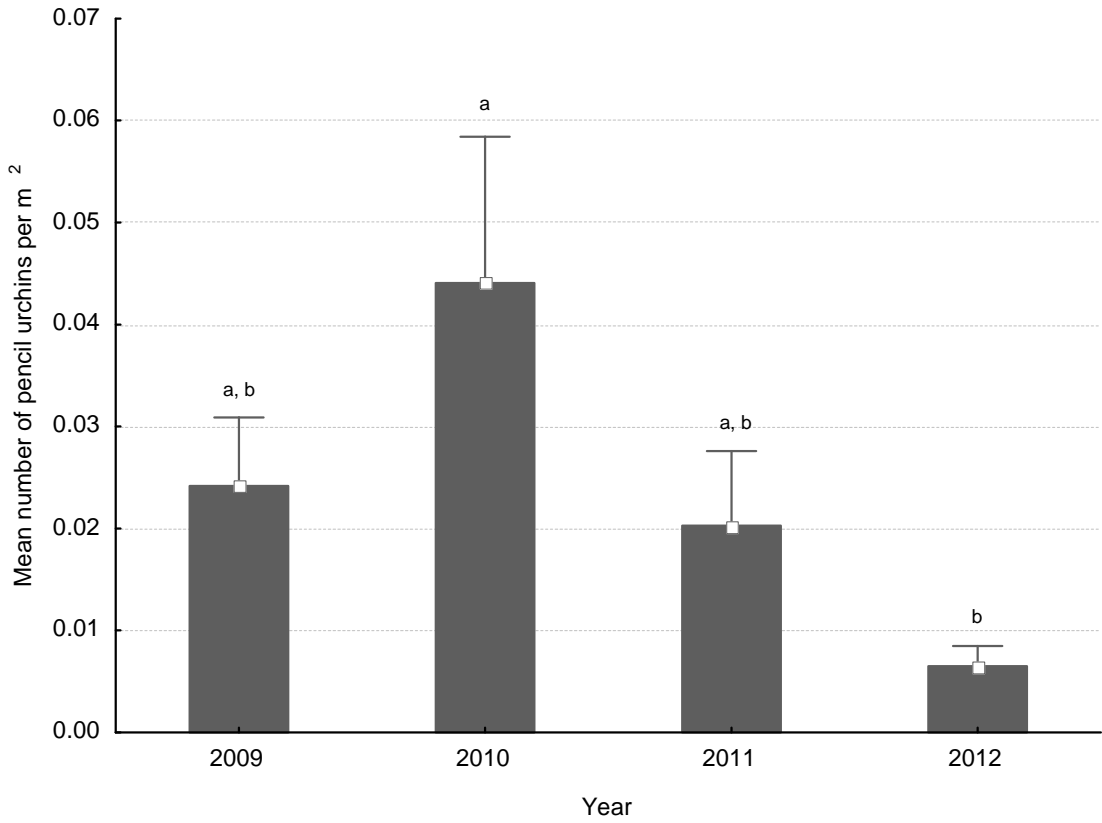


## Invertebrate community

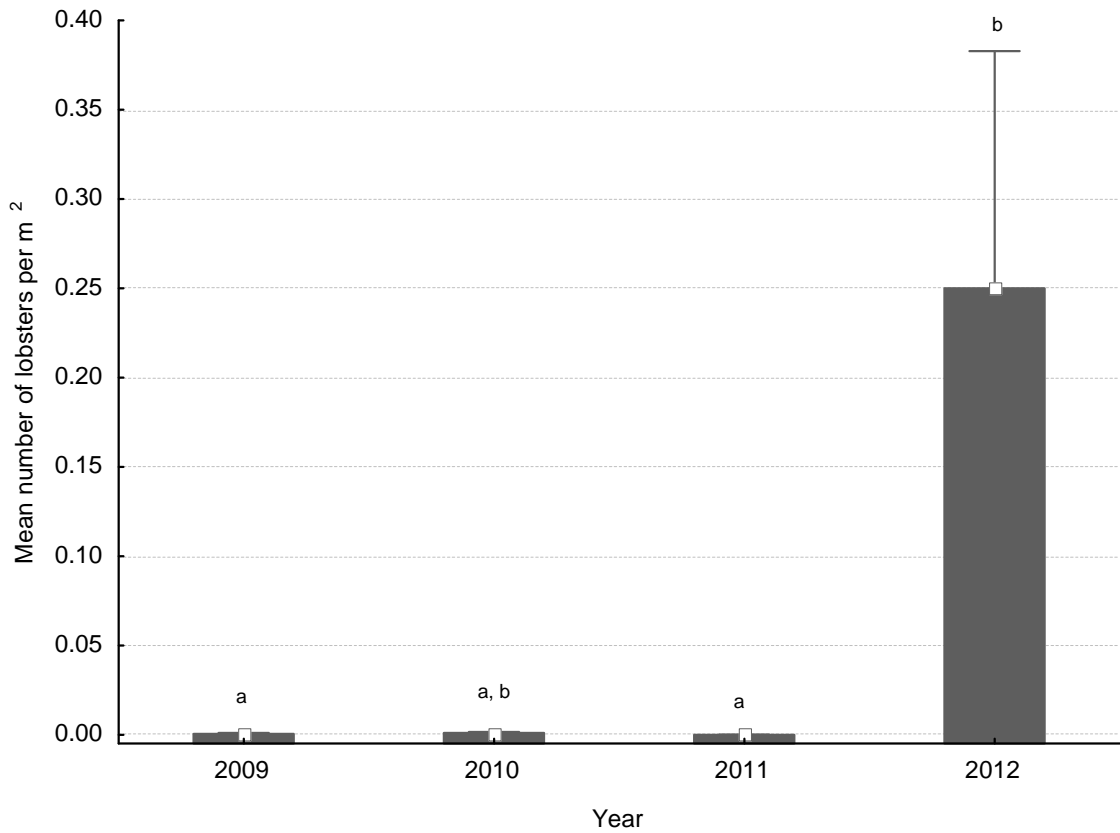
Invertebrates observations were almost entirely of *Diadema* urchins, accounting for an average 93% of all observations since 2009, with no significant differences between years (Figure 2.3e). Small significant changes in the pencil urchin population were observed with a decrease from 2010 to 2012 (ANOVA  $F_{(3,140)} = 3.5, p < .05$ ) (Figure 2.3f). From the seven groups of invertebrates counted, increases were only observed in the lobster population (ANOVA  $F_{(3,140)} = 3.4, p < .05$ ) (Figure 2.3g).



**Figure 2.3e.** Composition of the total invertebrates observations in north Musandam in 2009, 2010, 2011 and 2012. Values presented in percentages.



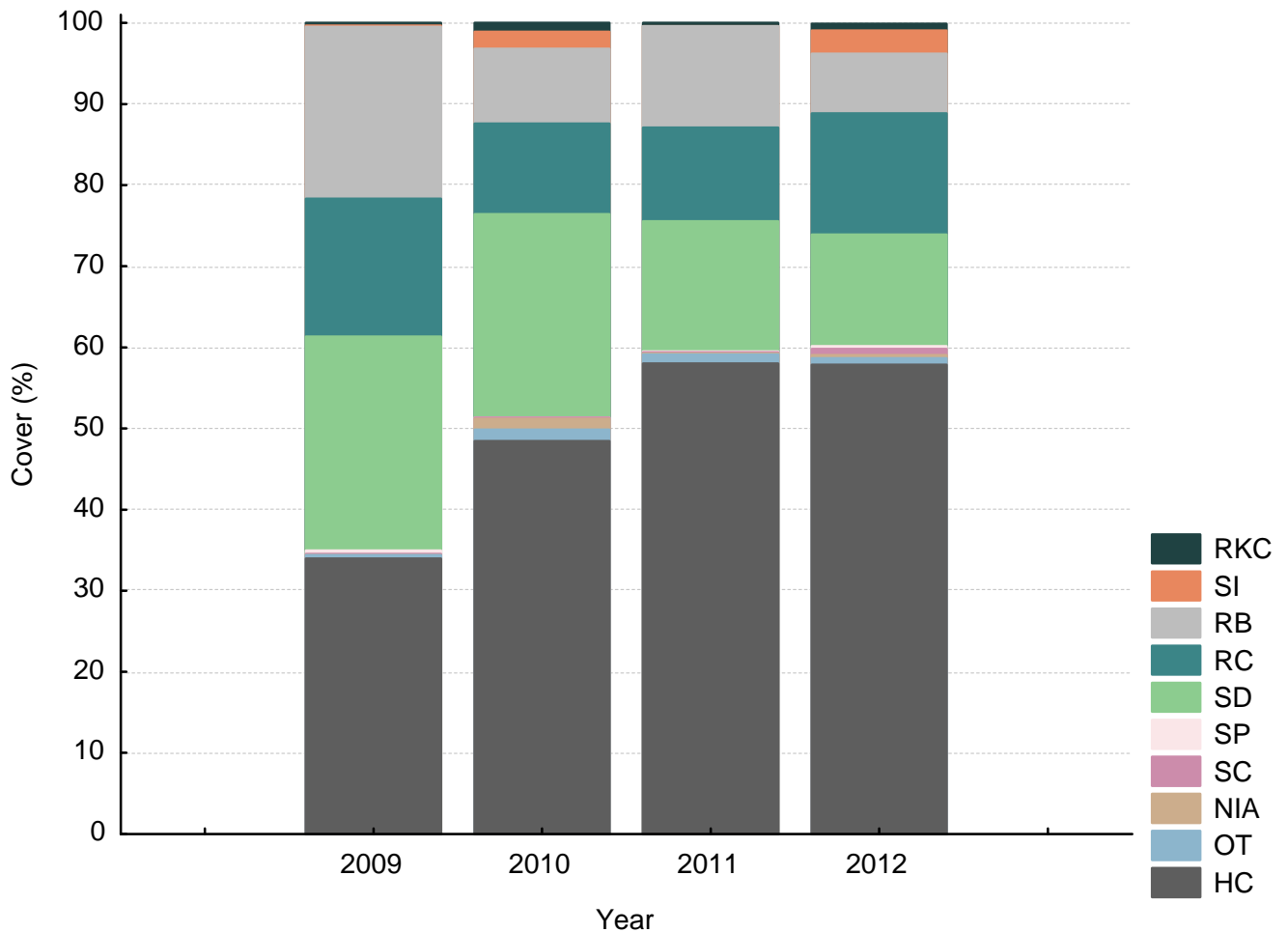
**Figure 2.3f.** Mean number of pencil urchins per m<sup>2</sup> in north Musandam. Lines represent standard error. Bars with different letters indicate significant differences (Tukey's tests,  $p < .05$ )



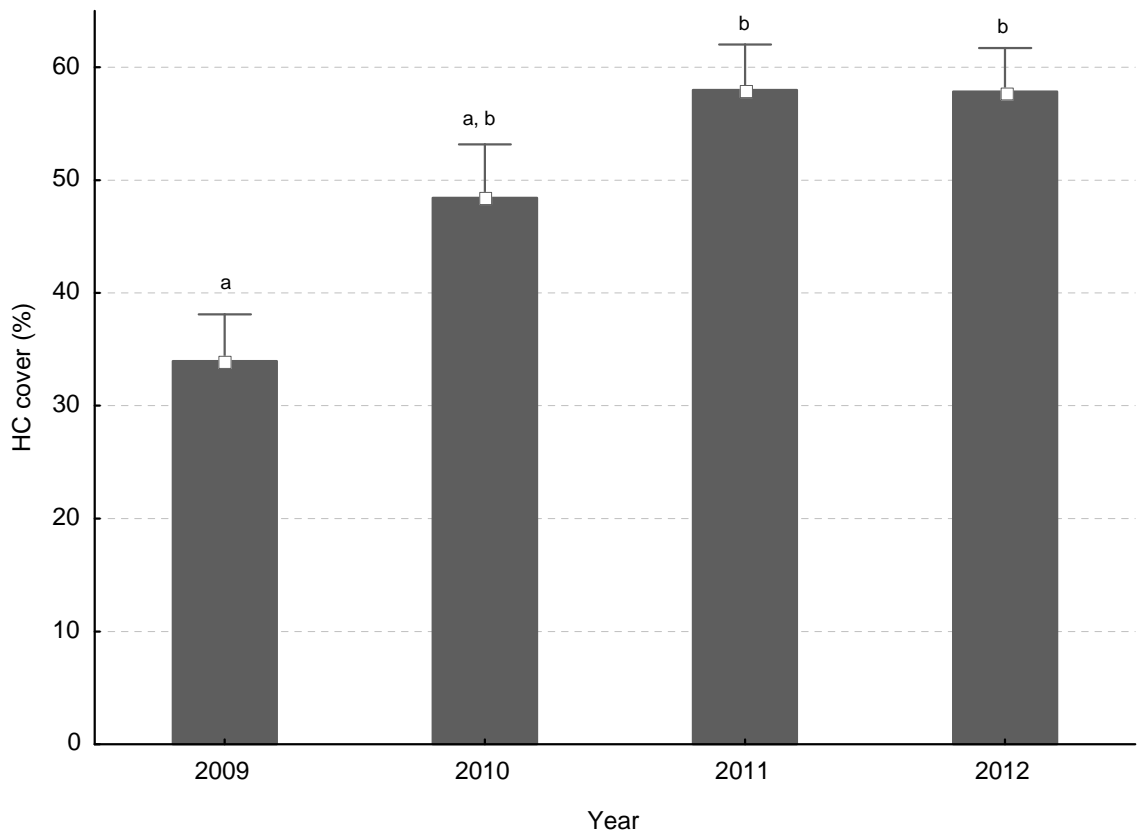
**Figure 2.3g** Mean number of lobsters per m<sup>2</sup> in north Musandam. Lines represent standard error. Bars with different letters indicate significant differences (Tukey's tests,  $p < .05$ )

## Substratum / benthic community

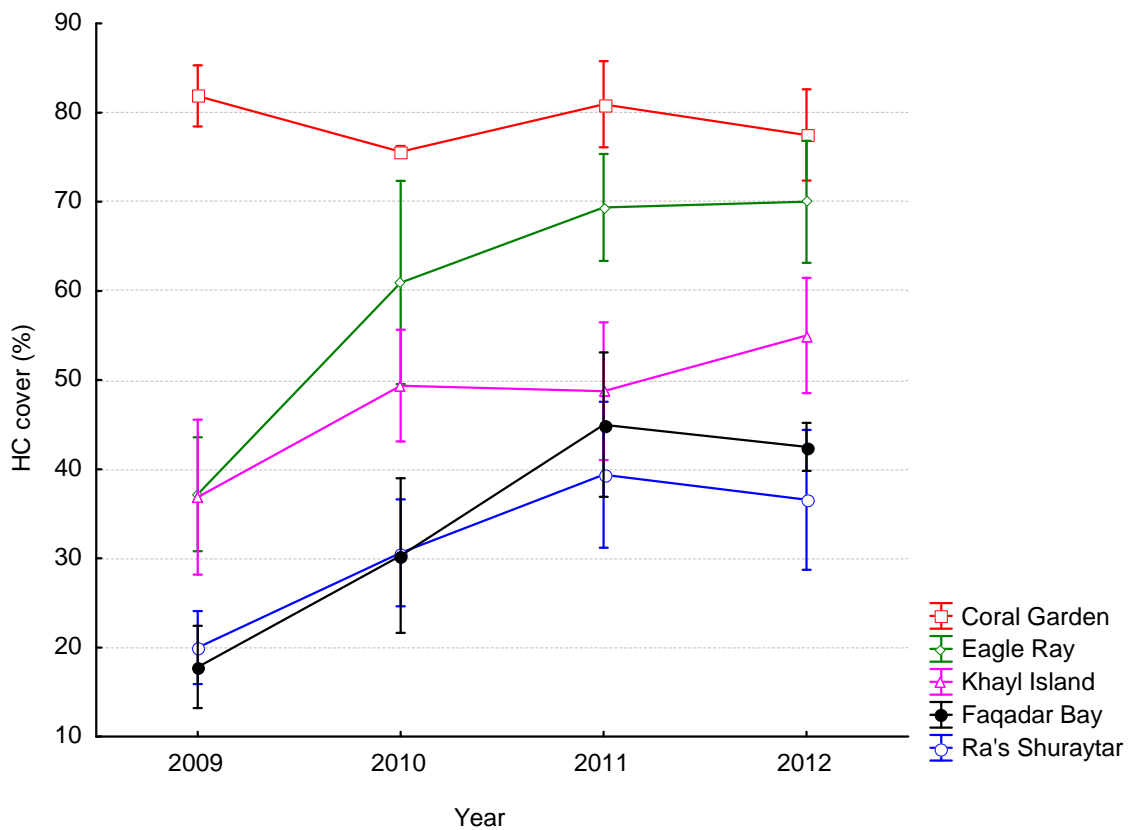
Our results show the importance of the north Musandam reefs, which presented high coral coverage. The main living substrate observed was hard coral (HC), followed by other living organisms (OT) and nutrient indicator algae (NIA). Even when putting all the ten Reef Check categories together, living and non-living, hard coral is still the main substrate encountered in north Musandam (Figure 2.3h and Figure 2.3i). This high coverage is principally seen at the Coral Garden dive site, which yielded the highest coral coverage ( $79.1 \pm 4.5\%$  SE). Eagle Ray and Khayl Island sites came next with coral cover mean values of  $59.4 \pm 4.5\%$  SE and  $47.5 \pm 3.7\%$  SE respectively (Figure 2.3j). In the living substrate categories, soft coral percentage cover showed a significant increase from the past years (ANOVA  $F_{(3,136)} = 4.8$ ,  $p < 0.05$ ) (Figure 2.3k).



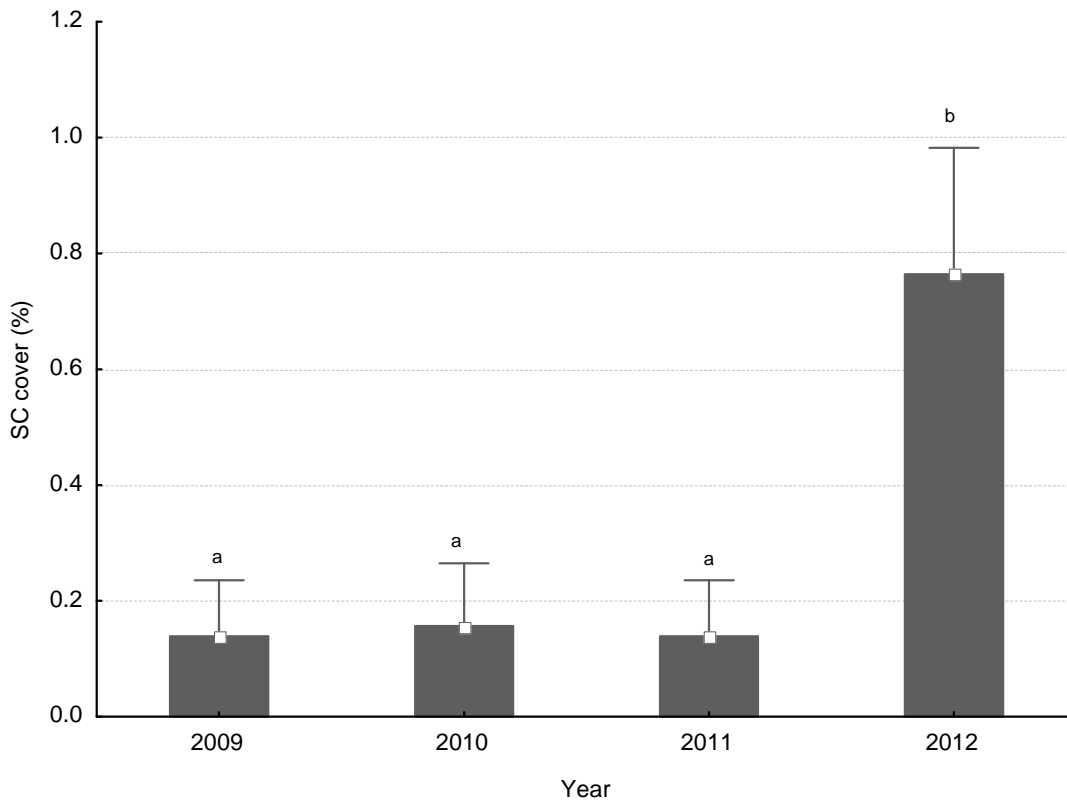
**Figure 2.3h.** Benthic composition of north Musandam study sites, from 2009 to 2012 (HC=hard coral; SC=soft coral; SP=sponge; NIA=nutrient indicator algae; OT=others; RKC=recently killed coral; RC=rock; RB=rubble; SD=sand; SI=silt).



**Figure 2.3i.** Mean hard coral (HC) percentage cover in north Musandam from 2009 to 2012. Lines represent standard error. Bars with different letters indicate significant differences (Tukey's tests,  $p < .05$ )



**Figure 2.3j.** Mean hard coral (HC) percentage cover at the five sites studied in north Musandam from 2009 to 2012. Lines represent standard error.



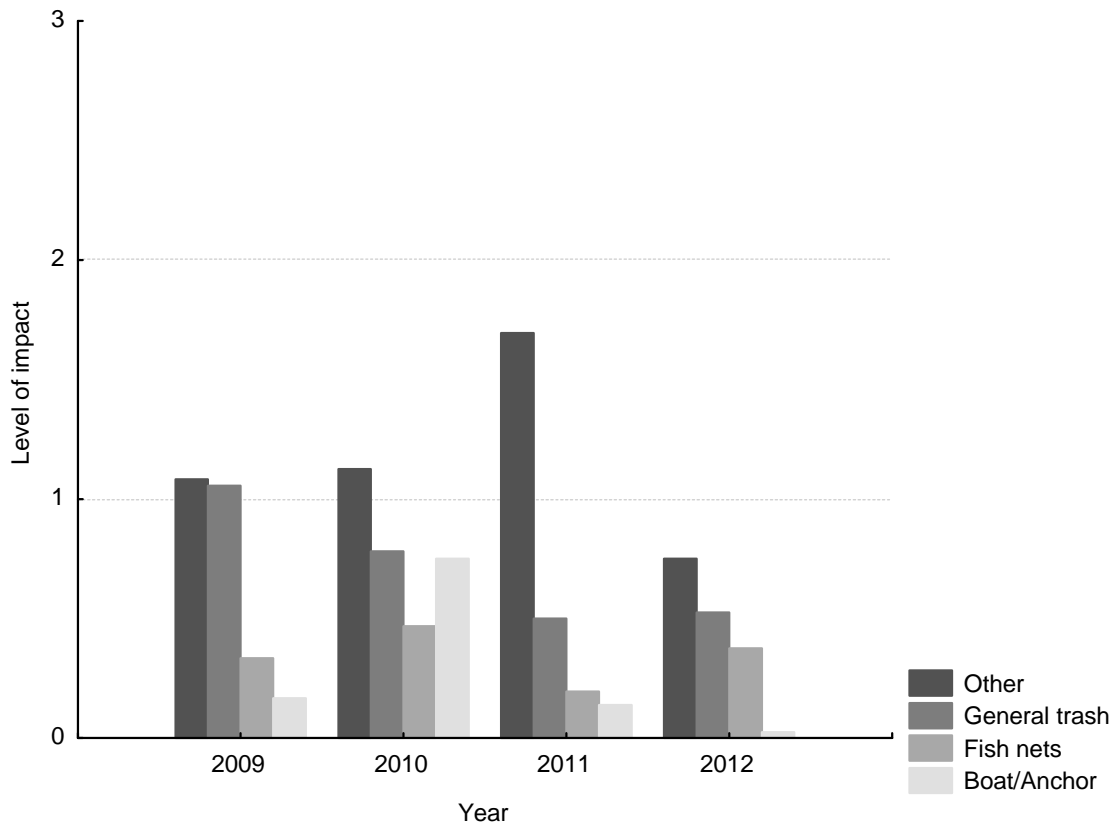
**Figure 2.3k.** Mean soft coral (SC) percentage cover in North Musandam from 2009 to 2012. Lines represent standard error. Bars with different letters indicate significant differences (Tukey's tests,  $p < .05$ )

### Underwater impacts, coral bleaching and coral disease

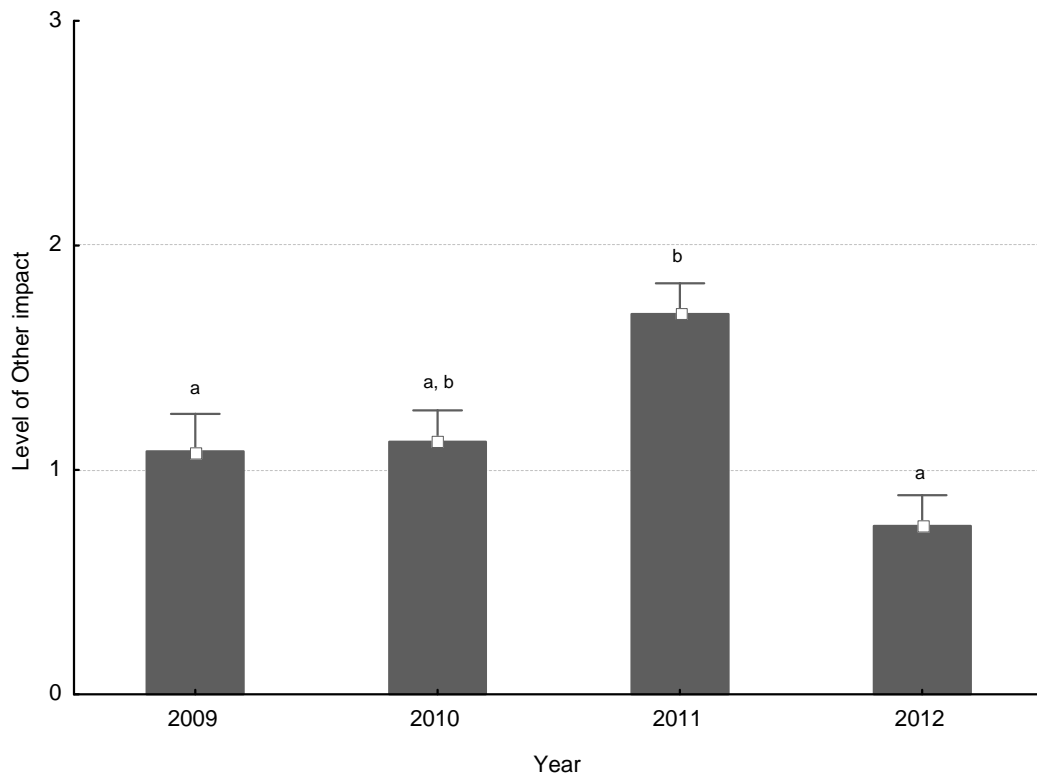
The 2012 expedition found the lowest underwater impacts since 2009. All impacts were on average below low-level (Figure 2.3l.). A significant decrease was seen from 2011 to 2012 in the group of 'Other' impacts, i.e. those impacts that do not include general trash, fish nets and boat/anchor damages ( $H_{(3,N=144)} = 21.2, p < 0.001$ ) (Figure 2.3m).

Bleaching in the coral colonies, or in the coral population, was still remarkably low in 2012. In average coral bleaching, in the colonies, has been around 3% since 2009 to 2012 (Figure 2.3n.). Coral disease was infrequent in 2012, and no significant changes from previous years were notice. The average percentage of coral colonies with disease per transect is as low as 0.1% (Figure 2.3o).

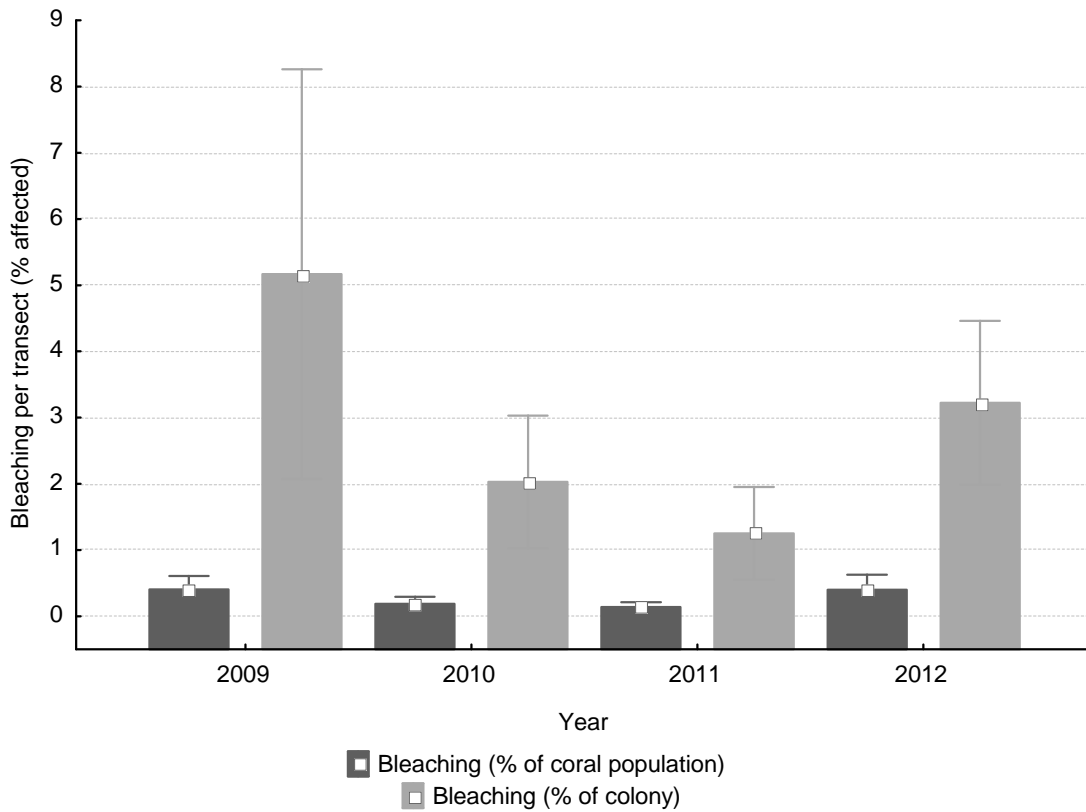




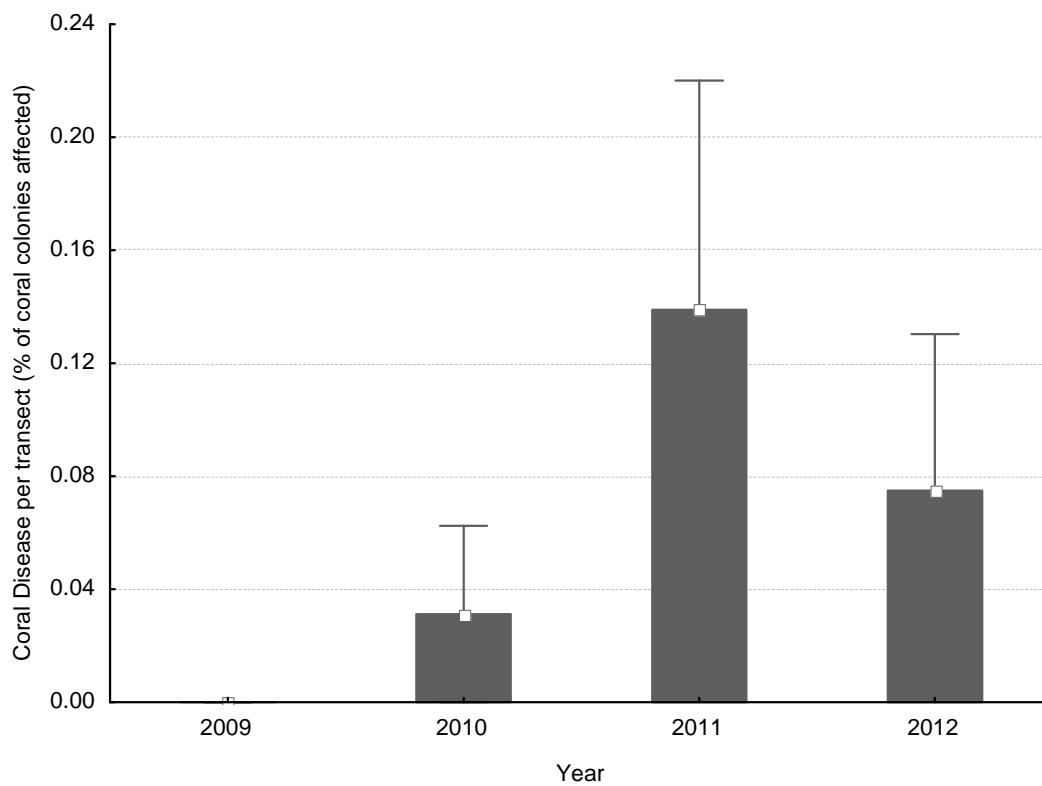
**Figure 2.3l.** Average level of underwater impacts found in north Musandam from 2009 to 2012 (Level of impacts: 0=none, 1=low, 2=medium and 3=high).



**Figure 2.3m.** Average level of Other impacts found underwater in north Musandam from 2009 to 2012 (Level of impacts: 0=none, 1=low, 2=medium and 3=high). Lines represent standard error. Bars with different letters indicate significant differences (Kruskal-Wallis's tests,  $p < .05$ )



**Figure 2.3n.** Mean percentage of coral colonies and coral population affected by bleaching from 2009 to 2012. Lines represent standard error.



**Figure 2.3o.** Mean percentage of coral colonies affected by disease from 2009 to 2012. Lines represent standard error.

## 2.4. Discussion & Conclusions

Surveys since 2009 suggest that the reefs of the North Musandam peninsula are stable, with a slight increase in hard coral cover and soft corals. When compared with the majority of the reefs in the Indo-Pacific region, it is clear that Musandam has a high coral coverage of almost 60%, making the area a rarity. However, some fish families continue to display worryingly low numbers, with the butterflyfish family showing a decrease in the population. The time to act and make the area an MPA (marine protected area) is now, while the reefs can still support a diversity of organisms because of this numbers of fish and invertebrates are able to recover. If more habitat is lost or degraded before protection is implemented, there is a good chance that fish and invertebrate populations will not be able to recover from their current very low numbers and that the current high coral coverage will be lost. Also, changes in one of the low and potentially unstable population groups (such as groupers, for example) may, in future, result in critical changes in other groups, as well as in the whole ecosystem (Pinnegar et al. 2000). As a result, the decrease in some fish and invertebrates families are likely to have future negative impacts on substrate composition and the reef ecosystem as a whole.

The main change noticed in the fish population in the analysis of the 2012 survey was in the decrease of butterflyfish (Chaetodontidae family). Chaetodontids are corallivores that predominately feed on individual coral polyps. In a healthy ecosystem, a balance between corallivore feeding intensity and coral regeneration has to exist so both populations can thrive. As butterflyfish only feed on the polyp, they only have a minor impact on coral growth. In general, coral cover correlates positively with the abundance of corallivores, and increases as corallivores increase (Cole et al. 2010). In north Musandam, our annual research expeditions show a steady growth in hard coral cover since 2009, indicating that the decrease seen in the butterflyfish population is probably not related to the decrease of food availability, but most probably to fishing, where normally species from this family are caught as bycatch.

Besides the changes in the butterflyfish population, there is still a worryingly low number of groupers and sweetlips. Many of the fish populations in the region are (too) heavily fished, and concerns that fishing effort have exceeded optimum levels for most species are now receiving some attention from local communities (Grandcourt et al. 2005). Fisheries that remove large individuals can easily erase all sexually mature fish and/or create a highly skewed sex ratio with the likelihood of reproductive failure (Sadovy and Vincent 2002). There is a strong need for conservation and management measures in this region, as well as more research in this field. An MPA and the studies that would need to be done in its creation, would provide this.

Since the beginning of our annual survey expeditions, north Musandam has shown a steady high coral coverage of nearly 60%; a value well above what is encounter in most reefs in other areas worldwide. Bruno and Selig (2007) in their research in the Indo-Pacific – where 75% of the world's coral reefs are located – showed that the region's average of coral cover was merely 22.1%, and only 1.8% of 390 reefs surveyed had coral cover higher than 60%. The high hard coral coverage in Musandam, and the increase in soft coral coverage, not only shows how vital it is to protect this area, but also how theses reefs, although located in an extreme marine environment, are resilient and able to succeed in such conditions. The fact that the reefs of the Musandam can survive such extremes of temperature and salinity has important implications for the rest of the world's reefs as climate change will make marine environments more acidic, saline and warmer. This is yet another reason why the reefs of the Musandam should be protected.

Previous studies conducted in Musandam have mentioned the issue of anthropogenic impacts in the region. Records of coral damage, pollution, and abandoned fishing equipment have been frequently reported in Musandam (Salm 1993, Salm et al. 1993). Although most of the coral reefs in Musandam occur quite far away from populated areas, there is still some evidence of damage. The location of some of the sites studied makes them more protected, and impact level can be kept low. Nevertheless, the frequent level of fishing activity by the local community in Musandam makes underwater impacts related to fisheries a constant observation in coral reef environment. More patrolling and awareness in the region should be created, to prevent the increase of pollution and fisheries-related impacts. Again an MPA could provide the framework for this.

Some of the damage observed on the reefs was not anthropogenic, but connected with the steep cliffs that characterise the Musandam. The collapse of coastal limestone is likely to be the cause for some of the damage seen underwater.

Sea surface temperature fluctuations observed in the Gulf are the largest encountered worldwide on reefs, ranging up to 24°C annually (Coles 2003, Sheppard and Loughland 2002). Despite this, corals in this region survive in what is considered extreme conditions for corals in other regions of the world. Since annual surveys began in 2009, north Musandam has shown few incidences of bleaching and disease during surveys in October, when seawater temperatures are below the average bleaching threshold. This observation concurs with previous studies that showed that coral reefs in this area are believed to be more resilient than coral in other regions worldwide (Burt et al. 2008, Wilkinson 2008). Bleaching events may happen in the summer, when higher temperatures prevail, but the area's strong currents with their well-mixed cooler water probably makes this area less prone to bleaching events than other regions of the Gulf (Salm et al. 1993). This too is a strong argument for an MPA in this locality.

Coral diseases, which can be caused by bacteria, cyanobacteria and fungi, are also of less concern in Musandam. They are in general related to anthropogenic influences and elevated water temperature (Cooper et al. 2009), which are not a primary concern at the moment in north Musandam. However, elevated seawater temperatures may increase the spread and virulence of pathogens, so due to the high temperatures that can be experienced in Musandam during summer, a recurrent observation of possible diseases is needed.

## **2.5. Recommendations & future expedition work**

The results from the annual 2009 to 2012 expeditions show clearly that Musandam Governorate has in its stewardship what are probably the best reefs of the region and a unparalleled area of natural beauty as well as commercial importance, not just for fishermen, but also for the local economy as a generator of income from tourism.

However, there is also demand and pressure on the reefs from the diving and fishing communities. The contrast values of a high coral coverage of almost 60% and the low average numbers of groupers and sweetlips show the potential that this ecosystem holds, but also that it is probably on the brink. Further regular surveys are needed as they will create a better understanding of population sizes and trends, as well as the trend in the magnitude of impacts and pressures for the area.

If environmental awareness can be created in time, and if the level of impacts can be controlled, there is a good chance that the number of species can be held steady or increased. Studies on Musandam ports fisheries landings would help understand the demands on this ecosystem, as well as its biodiversity and population levels. More information about the catch of groupers and sweetlips will provide a good indication of possible future trends for the area and the appropriate legal framework and enforcement needed in the Musandam region.

It is essential not to neglect the Musandam Peninsula and ensure that its marine environment is preserved. Involving local people in the surveys and explaining results, such as the relationship between high coral coverage and high species diversity, might be enough for the empiric understanding of a healthy ecosystem and control the pressure level of artisanal fisheries in Musandam. To understand the full impact of fishing in this region, studies on size classes, colour phases and social structure in the target population, such as groupers and sweetlips, should be conducted (Sadovy and Vincent 2002).

All the studies, new policies and regulations that could be applied in Musandam have to take into account the need to improve the social resilience by helping local communities to adapt to these changes. More strategies and approaches, done by management activities and planning for change are needed to minimise impacts and build resilience. To achieve this resilience, focus should primarily exist on land-based sources of pollution, over-fishing and climate change.

#### Musandam as a Marine Protected Network

A number of Marine Nature Reserves were declared in the 1990s by the Ministry of Environment and Municipality to protect vulnerable marine habitats in Oman (Siddeek 1999). There is Ras' Al-Had Nature Reserve for the protection of green turtle nesting grounds, Damaniyat Island Nature Reserve for the protection of green and hawksbill turtle nesting grounds, coral reefs, birds, and fish, Dhofar Khowrs Nature Reserve (fresh as well as brackish water lagoons) for the protection of sea birds and fish. All of these reserves are located outside Musandam Governorate and no protected area has been declared there yet. However, it is a stated government policy to have more reserves in each governorate.

Oman has only four areas that include significant coral growth. Besides Musandam, fringing reefs exists in the areas around Muscat (including the Daymaniyat Islands), the Masirah area, and the bays of Dhofar and Al Halaniyat Island. Nevertheless, only in Musandam is there a true framework development, where the coral rock substrate thoroughly covers the bedrock (Salm et al. 1993).

We therefore recommend the implementation of a new marine protected area (MPA) in Musandam Governorate or a network of MPAs for the protection of this unique marine environment. In this context it is encouraging to note that other studies (e.g. Al-Cibahy et al. 2012) have also started to suggest the implementation of appropriate legal protection on this unparalleled ecosystem. The Musandam is an ideal place for an MPA or MPAs as impacts and population levels are still relatively low and coral coverage is high. Having said this, although there was an increase in some valuable substrate cover, the low number of some groups of fish and invertebrates shows that this coral reef system may be at the threshold of collapse, and the increase of some impacts is a concern. It is crucial to protect the areas that have higher coral coverage and biodiversity. Coral Garden reef site is the ideal place to have as part of the MPA, with a high average coral cover of 79%. Its location, on the top of Musandam, where the currents are stronger, and its location further away from the city of Khasab makes it an ideal place for the core of a future MPA.

Furthermore, the military presence in Musandam, due to its location in the Strait of Hormuz, may also be significant for the implementation of an MPA. Military exclusion zones could form part of an MPA, and the policing of protected areas could be done by the military with relatively little additional training and costs.

The implementation of one or more MPAs will help to mitigate the impacts of stresses found by the expedition, as well as create benefits such as (a) conserve biological diversity and associated ecosystems that cannot survive in most intensely managed seascapes; (b) promote natural age structures in populations, increasing fish catches locally (by protecting critical spawning and nursery habitats) and in surrounding fishing grounds; (c) provide shelter for species that cannot survive in areas that continue to be fished; (d) provide alternative incomes for local communities and alleviate poverty; (e) protect sensitive habitats from disturbances and damage from fishing gear; (f) eliminate “ghost fishing” by lost or discarded gear; (g) serve as point of reference of undisturbed control reference sites that can be used as a baseline for scientific research and also to determine fishery effects in other areas and thereby help to improve fisheries management, and (h) act as focal points for public education and awareness on marine ecosystems and human impacts upon them (IUCN-WCPA 2008).

The Musandam Peninsula or parts of it could also be established as a Biosphere Reserve under UNESCO’s Man and the Biosphere (MAB) Programme. Biosphere Reserves are areas of terrestrial, coastal and marine ecosystems established to promote and demonstrate harmonious and sustainable interactions between biodiversity conservation and socio-economic well-being of people, through research, education, monitoring, capacity building and participatory management. By being protected under this classification, UNESCO can provide advice and occasionally source funds to develop local efforts; it can also help broker projects or set up stable financial mechanisms.

Knowing that implementing an MPA can take several years to accomplish, it is necessary to make additional steps until an MPA is in place. We, therefore, recommend the following actions:

- Deployment and maintenance of standardised mooring buoys in all known dive sites would help to reduce the impacts of anchor and boat damage.
- Create, implement and police regulations for the diving industry, such as (1) regulating the number of boats and divers allowed per dive site, (2) not permitting anchoring and (3) rules to have an obligatory dive guide from the dive centres with every dive group.
- Standard signs, information, and visitor logbooks should be enforced in all dive centres conducting dives in Musandam to provide adequate interpretative visitor information regarding Musandam and also to serve as a first control of the number of divers in the area.

Involving the local community in future studies is extremely valuable in order to mitigate the lack of awareness and knowledge. If awareness can be created in time and if the impacts can be controlled, then there is a good chance that the number of species can be held stable or increased.

Studies on Musandam ports fisheries landings will help understand the demands of this ecosystem, as well as its biodiversity and population levels. Future Reef Check surveys on the Musandam Peninsula will also help to understand population trends and sizes of indicator species, as well as the persisting pressures on the area.



## 2.6. References

- Al-Cibahy, A.S., Al-Khalifa, K., Böer, B., and Samimi-Namin, K. (2012). Conservation of Marine Ecosystems with a Special View to Coral Reefs in the Gulf. In *Coral Reef of the Gulf. Adaptation to Climatic Extremes*, B.M. Riegl, and R.E. Dodge, eds. (Springer).
- Anderson, D.M. (1997). Turning back the harmful red tide. *Nature* 388, 513-514.
- Baker, A.C., Starger, C.J., R.McClanahan, T., and Glynn, P.W. (2004). Corals' adaptive response to climate change. *Nature* 430, 741.
- Bauman, A.G., Burt, J.A., Feary, D.A., Marquis, E., and Usseglio, P. (2010). Tropical harmful algal blooms: An emerging threat to coral reef communities? *Marine Pollution Bulletin* 60, 2117-2122.
- Bruno, J.F., and Selig, E.R. (2007). Regional Decline of Coral Cover in the Indo-Pacific: Timing, Extent, and Subregional Comparisons. *PLoS ONE* 2, e711.
- Buddemeier, R.W., Baker, A.C., Fautin, D.G., and Jacobs, J.R. (2004). The Adaptive Hypothesis of Bleaching. In *Coral Health and to Disease* E. Rosenberg, and Y. Loya, eds. (Berlin, Germany: Springer ), pp. 427-444.
- Burt, J., Bartholomew, A., and Usseglio, P. (2008). Recovery of corals a decade after a bleaching event in Dubai, United Arab Emirates. *Marine Biology* 154, 27–36.
- Carpenter, K.E., Krupp, F., Jones, D.A., and Zajonz, U. (1997). The living marine resources of Kuwait, Eastern Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates (Rome: FAO).
- Claereboudt, M.R.G., Al-Oufi, H.S., McIlwain, J., and Goddard, J.S. (2004). Relationships between fishing gear, size frequency and reproductive patterns for the kingfish (*Scomberomorus commerson Lacépède*) fishery in the Gulf of Oman. In *Management of Shared Fish Stocks*, A.I.L. Payne, C.M. O'Brien, and S.I. Rogers, eds. (Oxford: Blackwell), pp. 56-67.
- Cole, A., Lawton, R., Pratchett, M., and Wilson, S. (2010). Chronic coral consumption by butterflyfishes. *Coral Reefs*, 1-9.
- Coles, S.L. (2003). Coral species diversity and environmental factors in the Arabian Gulf and the Gulf of Oman: a comparison to the Indo-Pacific Region. *Atoll research bulletin* 507, 19.
- Cooper, T.F., Gilmour, J.P., and Fabricius, K.E. (2009). Bioindicators of changes in water quality on coral reefs: review and recommendations for monitoring programmes. *Coral Reefs* 28, 589-606.
- EWS-WWF (2008). Coral reef investigations in Abu Dhabi and Eastern Qatar. Final Report. January 2005 - December 2007. (Dubai, EWS-WWF), p. 72.
- Fraser, F.C., Falcon, N.L., Falcon, M., Cornelius, P.F.S., Hugh-Jones, P., Bertram, G.C.L., Shearman, D.J., Glennie, K.W., Glennie, M., Shotton, F.W., *et al.* (1973). The Musandam Expedition 1971-72 Scientific Results: Part I: Discussion. *The Geographical Journal* 139, 422-425.
- Grandcourt, E.M., Al Abdessalaam, T.Z., Francis, F., and Al Shamsi, A.T. (2005). Population biology and assessment of the orange-spotted grouper, *Epinephelus coioides* (Hamilton, 1822), in the southern Arabian Gulf. *Fisheries Research* 74, 55-68.
- Grimsditch, G.D., and Salm, R.V. (2006). *Coral Reef Resilience and Resistance to Bleaching* (Gland, Switzerland: IUCN).

- Henderson, A.C., McIlwain, J.L., Al-Oufi, H.S., and Al-Sheili, S. (2007). The Sultanate of Oman shark fishery: Species composition, seasonality and diversity. *Fisheries Research* 86, 159-168.
- Hinchley, D., Lipsett-Moore, G., Sheppard, S., Sengebau, F.U., Verheij, E., and Austin, S. (2007). Biodiversity Planning for Palau's Protected Areas Network: An Ecoregional Assessment TNC Pacific Island Countries (South Brisbane, Australia, The Nature Conservancy, Indo-Pacific Resource Centre).
- Hodgson, G., Hill, J., Kiene, W., Maun, L., Mihaly, J., Liebeler, J., Shuman, C., and Torres, R. (2006). Reef Check Instruction Manual: A guide to Reef Check Coral Reef Monitoring (California, USA: Reef Check Foundation ).
- IUCN-WCPA (2008). Establishing Marine Protected Area Networks—Making It Happen. (Washington, D.C, IUCN-WCPA, National Oceanic and Atmospheric Administration and The Nature Conservancy), p. 118.
- Marshall, I.P., and Schuttenberg, H. (2006). A Reef Manager's Guide to Coral Bleaching. (Townsville, Australia, Great Barrier Reef Marine Park Authority), p. 166.
- McClanahan, T.R., Sheppard, C.R.C., and Obura, D.O., eds. (2000). Coral Reefs of the Indian Ocean: Their Ecology and Conservation (NY: Oxford University Press ).
- Mooney, C. (2007). Storm World: Hurricanes, Politics, and the Battle Over Global Warming (Tantor Media, Inc).
- Pilcher, N.J., Wilson, S., Alhazeem, S.H., and Shokri, M.R. (2000). Status of coral reefs in the Arabian/Persian Gulf and Arabian Sea region (Middle East). In Status of Coral Reefs of the World: 2000, W. C., ed. (Townsville, Australia: Australian Institute of Marine Science), pp. 55-64.
- Pinnegar, J.K., Polunin, N.V.C., Francour, P., Badalamenti, F., Chemello, R., Harmelin-Vivien, M.-L., Hereu, B., Milazzo, M., Zabala, M., D'Anna, G., and Pipitone, C. (2000). Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. *Environmental Conservation* 27, 179-200.
- Pous, S.P., Carton, X., and Lazure, P. (2004). Hydrology and circulation in the Strait of Hormuz and the Gulf of Oman-Results from the GOGP99 Experiment: 2. Gulf of Oman. *J Geophys Res* 109.
- Price, A.R.G., Sheppard, C.R.C., and Roberts, C.M. (1993). The Gulf: Its biological setting. *Marine Pollution Bulletin* 27, 9-15.
- Randall, J.E. (1995). Coastal Fishes of Oman (Honolulu: University of Hawaii Press).
- Reynolds, R.M. (1993). Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman--Results from the Mt Mitchell expedition. *Marine Pollution Bulletin* 27, 35-59.
- Rezai, H., Wilson, S., Claereboudt, M., and Riegl, B. (2004). Coral reef status in the ROPME sea area: Aranian/persian gulf, gulf of Oman and Arabian. In Status of Coral Reef of the World 2004, C. Wilkinson, ed., pp. 155-170.
- Richlen, M.L., Morton, S.L., Jamali, E.A., Rajan, A., and Anderson, D.M. (2010). The catastrophic 2008-2009 red tide in the Arabian gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagellate *Cochlodinium polykrikoides*. *Harmful Algae* 9, 163-172.
- Riegl, B. (1999). Corals in a non-reef setting in the southern Arabian Gulf (Dubai, UAE): fauna and community structure in response to recurring mass mortality. *Coral Reefs* 18, 63-73.

- Riegl, B. (2001). Inhibition of reef framework by frequent disturbance: examples from the Arabian Gulf, South Africa, and the Cayman Islands. *Palaeogeography, Palaeoclimatology and Palaeoecology* 175, 79-101.
- Riegl, B.M., Purkis, S.J., Kohler, K.E., and Dodge, R.E. (2006). Spatial patterns in Arabian Gulf coral assemblages (Jebel Ali, Dubai, U.A.E.) in response to temperature-forcing. In 10th International Coral Reef Symposium, pp. 683-687.
- Sadovy, Y.J., and Vincent, A.C.J. (2002). Ecological Issues and the Trades in Live Reef Fishes. In *Coral Reef Fishes. Dynamics and diversity in a complex ecosystem*, P.F. Sale, ed. (San Diego: Elsevier Press), pp. 391-420.
- Salm, R.V. (1993). Coral reefs of the Sultanate of Oman. *Atoll research bulletin* 380, 85 pp.
- Salm, R.V., Jensen, R.A.C., and Papastavrou, V. (1993). Shallow water corals. In *Marine fauna of Oman: Cetaceans, turtles, seabirds, and shallow water corals* (Gland, Switzerland: IUCN in collaboration with the Sultanate of Oman (Gland, Switzerland)), pp. 41-66.
- Sheppard, C., Price, A., and Roberts, C. (1992). *Marine Ecology of the Arabian Region: Patterns and processes in extreme tropical environments* (Toronto: Academic Press).
- Sheppard, C.R.C., and Loughland, R. (2002). Coral mortality and recovery in response to increasing temperature in the southern Arabian Gulf. *Aquatic Ecosystem Health and Management* 5, 395-402.
- Siddeek, M.S.M. (1999). Marine fisheries resources, fisheries and marine environmental management, coral reefs and marine parks in the Northwest Indian Ocean In *Regional Workshop on Fisheries Monitoring, Control and Surveillance* (Muscat), pp. 101-115.
- SOMER (2003). *State of the Marine Environment Report*. (Kuwait, Regional Organization for the Protection of the Marine Environment), p. 217.
- Spalding, M., Ravilious, C., Green, E.P., and UNEP-WCMC (2001). *World Atlas of Coral Reefs* (University of California Press).
- Subba-Rao, D.V., and Al-Yamani, F. (1998). Phytoplankton ecology in the waters between Shatt Al-Arab and Straits of Hormuz, Arabian Gulf: A review. *Plakton Biology and Ecology* 45, 101-116.
- UNEP (2008). *UNEP Year Book 2008: An Overview of Our Changing Environment*. P. Harrison, ed. (Nairobi, Kenya, UNEP Division of Early Warning and Assessment (DEWA)).
- Wilkinson, C. (2004). *Status of Coral Reefs of the World: 2004* (Townsville, Australia: Australian Institute of Marine Science).
- Wilkinson, C.R. (2008). *Status of coral reefs of the world : 2008* (Townsville, Australia: Global Coral Reef Monitoring Network, Reef and Rainforest Research Centre).
- Wilson, S., Fatemi, S.M.R., Shokri, M.R., and Claereboudt, M. (2002). Status of Coral Reefs of the Persian/Arabian Gulf and Arabian Sea region. In *Status of Coral Reefs of the World: 2002*, W. C, ed. (Townsville, Australia: Australian Institute of Marine Sciences), pp. 53-62.

## Appendix I: Expedition diary and reports



A multimedia expedition diary is available on <http://biosphereexpeditions.wordpress.com/category/expedition-blogs/musandam-2012/>



All expedition reports, including this and previous expedition reports, are available on [www.biosphere-expeditions.org/reports](http://www.biosphere-expeditions.org/reports).